Boojum Research Limited

ECOLOGICAL ENGINEERING

TESTS OF CONCEPTS AND ASSUMPTIONS ON LEVACK

YEAR 1: ECOLOGY

BY

M.KALIN

IN FULFILLMENT OF INCO CONTRACT # A9761

AND

CANMET/RATS CONTRACT

DEPARTMENT OF SUPPLY AND SERVICES

23 SQ 23440-S-9119

MARCH 1986

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SUMMARY

The objectives and results of the Ecological Engineering endeavours conducted on the Levack tailings by Boojum Research Ltd. as part of an INCO/RATS/Boojum agreement, are summarized in the five sections below. The first section covers methods for establishing and promoting the expansion of cattail stands. The second considers the various waste water distribution systems tested. The third deals with the selection of suitable species for establishment on extreme acid or alkaline areas. The fourth examines methods of oxygen measurements in the root zones of various vegetation covers and considers the relationship to acid generation as well as outlining the results of preliminary efforts to establish and promote a moss cover on acid and alkaline tailings. Finally, the fifth section summarizes the chemical, physical and biological analysis of a seepage creek with the aim of developing a self-sustaining seepage treatment system for close-out.

1. Establishment and Expansion of Cattail Stands

The major "macro" vegetation on wet or water-logged areas of inactive acidic or alkaline tailings are cattails (Typha spp.). Determining methods for increasing the density, standing crop and rate of expansion of existing cattail stands and for initiating new stands through transplanting techniques are major aims of Ecological Engineering. Increasing biomass production will increase the amount of organic matter which in turn provides a suitable habitat for a succession of plants following mine close-out when there is insufficient water to support cattail growth. On acidic tailings, a build-up of layers of organic matter would also assist in reducing acid generation.

The experiments with cattails therefore address problems of expansion and biomass production. An indicator of the potential for a cattail stand to expand was needed primarily as a measure of stand dynamics. It was found that the ratio of the number of juvenile individuals to the number of mature individuals was a suitable indicator. Certain cattail stands were producing few juvenile shoots, i.e. had a low stand expansion potential. This ratio was correlated with the depth of the underground stem (=rhizome) which sends new shoots up to the sediment surface. In cattail stands where rhizomes were deep and mine slime compacted, the ratio was low (e.g. 0.2); in stands where the rhizomes were shallow and the slimes were not compacted, the ratio was higher (e.g. 0.6).

The compacted layers of mine slimes and lime appeared to present a physical barrier which growing juvenile shoots could not penetrate. A series of sediment cultivation experiments was set up to address this hypothesis. The results will be obtained in spring, 1986, and will indicate whether cultivation of root beds would assist cattail stand expansion. Mature cattail plants were successfully tranplanted to "vacant" areas on the mine slimes. In these newly created cattail stands, the parent transplants produced numerous juvenile plants. The stand expansion potential ratio was 1.4, indicating vigorous growth.

Although there was an abundance of young cattail seedlings covering mine slimes in the beginning of the summer, the majority of the seedlings perished before the end of the summer despite experiments with various mulching

techniques. Occasionally small pockets survived, but this could not be attributed to the application of mulches. However, fertilization experiments carried out with these seedlings in early August produced remarkable growth and the seedlings were still healthy in mid-September. Should the cattail seedlings survive and continue to grow in 1986, more emphasis would be placed on methods which maintain the cattail seedling populations after germination in early summer.

2. Waste Water Distribution Systems

Of the waste water distribution systems tested, the linear spray system was found most suited for moss cover development. Although it required considerable maintenance and resulted in the formation of small channels, the area was kept reasonably moist. The circular spray is easy to install and low in maintenance. This spray, however, resulted in considerable movement of the "fines" on the surface which could counteract attempts to establish a moss cover. The linear spray system is, therefore, recommended as the best system for supplying acidic water for acidophilic moss cover experiments in the 1986 program.

The alkaline waste water from the sand plant and from the mine was most effectively distributed over the the pyrrhotite by intercepting the waste stream with low boomerang dams. Suspended silty particles settled out behind them creating an alkaline cover over the pyrrhotite tailings. Cattails were transplanted into the accumulated slurry to test if they would serve to stabilize the system. This dam system showed promise and should be developed further.

A successfully established vegetation cover on the alkaline waste water distributed during the last phase of operation of acid generating tailings area would, at the time of close out, lead to a surface with vegetation, rooted in alkaline wastes hence not penetrating into the acid generating material below. In effect, if this method can be perfected it could be utilized most suitably in a planned shut-down. It can generally be expected that during the last several months of mine operation, waste water could be effectively re-directed for use in close-out of waste management area, reducing problems of acid generation.

3. Species Selection for Extreme Conditions

Indigenous plant species are generally emphemeral, and only pockets persists on the tailings areas. The dynamics of these populations form an important part of Ecological Engineering, so it is important to develop an understanding of the factors controlling their distribution.

The indigenous population of plants on Levack consisted mainly of horsetail (<u>Equisetum</u> spp.), field sorrel (<u>Rumex</u> <u>acetosella</u>), various grasses, and several mosses. A permanent transect was established to monitor the dynamics of these indigenous populations throughout the first year and in subsequent years of the program. This kind of classical ecological information would provide baseline data against which one could compare and evaluate the flora resulting from (or in response to) the implementation of various Ecological Engineering methodologies in years to come.

A wetland is a diversified association of aquatic and semi-aquatic plants. One important objective was to determine if rushes, sedges and grasses commonly found as constituents in wetlands flora will tolerate the alkaline conditions and if they are suitable for transplanting. This was tested in boxes set up along the shoreline of the mine water retention pond. The aquatic plants, Potomogeton and Chara, did not survive in conditions present in the mine water retention pond. Other transplanted species including reed grass (Phragmites), a rush (Juncus) and a sedge (Carex) not only survived transplanting from the Falconbridge Conservation Area into the Levack mine water retention pond, but produced new shoots and "runners". The over-wintering ability of these newly established plants will be monitored in the spring of 1986.

An acid creek on the tailings was dammed in order to provide an acidic water supply with extreme physical and chemical characteristics due to contact with the highly reactive pyrrhotite. The presence of the dams served two experimental purposes: (1) to determine if the introduced acidophilic biota such as algae, aquatic mosses and hydroponically-grown cattails could be established in this water and survive into the following year(s); and (2) to create a system in which the the observations and principles reported from research on acid mine drainage in coal mining areas in particular, could be applied in order to develop a layer of refractory organic material which could result in beneficial effects on water quality. Both aspects could be studied in 1986 as long as a sufficient water supply is available. The damming resulted in ideal conditions, with the formation of three compartments in the creek which provide different water depths for a series of experiments. The aquatic mosses and hydroponic cattail experiments have been initiated and the over-wintering capacity of the transplanted species will be monitored in the spring of 1986.

4. The Root Zone of Vegetation - Acid Generation and Establishment and Expansion of Moss Covers

A literature review of the oxygen measurement which might be applicable to differentiate between effects of various vegetation covers on acid generation indicated that a costly test system would be required. Many parameters to design the system appropriately are not known. It was recommended that a systematic collection of field observations on root zones be done before a quantitative system to measure oxygen penetration can be developed.

Moss covers on acid-generating tailings are frequently quite dense and are believed to reduce water and air infiltration into the tailings thus reducing acid generation. If methods can be developed to establish a terrestrial self-maintaining moss cover, this may lead to acid generation reduction on dry surfaces of tailings areas. Acidophilic moss protonemata were transplanted by different techniques onto pyrrhotite. Some growth and spreading of fine moss filaments were seen in an experimental plot in which the pyrrhotite had been amended with sand and where the moss had been mixed into the tailings as a slurry. Alkaline mosses were successfully transplanted onto newly deposited mine slime surfaces. Fertilizer amendments containing N-P-K were applied to undisturbed (not cultivated) mine slime surfaces where the moss cover was sparse. The amendment stimulated vigorous growth and expansion of the moss cover. Straw compared to cotton tailings as mulch for moss cover promotion gave good indications of positve effects.

5. Seepages from tailings: the seepage creek

The objective was to describe in detail the chemical, physical and biological characteristics of a seepage creek and to attempt a synthesis of ongoing chemical and physical processes to develop concepts on long-term seepage treatments. Nine stations at 50 m intervals along the creek were monitored for chemical and physical data (July, August and September) and the biology of the stream was described.

The organic matter (living and dead) in the seepage creek appears to provide a catalytic surface for precipitation of iron hydroxide from the water. Steady iron removal occurs over the upper 250 m of the creek. The hydraulic retention time of the creek water increases as the water enters a broad expanse (=pond) of brome grass. A 6.5-fold reduction in total soluble iron occurs across this area (to a level of 0.2 ppm) along with a concomittant drop in pH of 2 full units. The latter acidification resulted in a re-solution of Ni and some Zn.

The results indicate that a self-maintaining treatment system for seepages has to consist of a two step biological polishing system. At the head of the seepage, an alkaline or neutral ecosystem has to remove iron and this should be followed by an acidic ecosystem which will remove dissolved heavy metals. The growth dynamics of the ecosystem have to be integrated with the physical flow characteristics of the seepage.

ACKNOWLEDGEMENTS

Ecology may well be the mainstay of Ecological Engineering, however the application to tailings abandonment depends on the effective integration of other disciplines. Most important is the assistance of the operator, INCO, to whom our foremost acknowledgement is due for the realisation of this project.

Boojum wishes to thank J. Smith and G. Davis, Mine Management (Levack) for their cooperation and interest in the project. The excellent services and results provided by the Analytical Chemistry Laboratory under the supervision of B. Andrew, are greatly appreciated. Without the committment, inventiveness and understanding of D. Bolton, the project coordinator, and his staff from INCO Agriculture, this project would not have overcome many impossible tasks.

The enthusiatic help provided by the INCO summer students especially W. Warren and M. Languille, was much appreciated. The excellent supervision by B. Dreisinger, who orchestrated the interactions of Boojum with the various groups within INCO and those of the Contract Agencies is gratefully acknowledged. We thank J. McKinnon for the smooth handling of all legal and adminstraive matters associated with the project.

Boojum is also indebted for the excellent performance of the subcontractors from MacLaren Plansearch Inc. The committment from J. Roberts and T. Chart to the project was invaluable and is greatly appreciated.

Finally but most importantly, I am deeply indebted to my staff, R. Buggeln, M. Olaveson, R. Chan and M. Smith, who, with their determination, perseverance and dedication, made this project possible. Without their expertise and ingenuity, the project would have failed to demonstrate the fundamental principles of Ecological Engineering.

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1. INTRODUCTION

1.1. Background

Conventional methods in reclamation of tailings areas have been very successful. However, their effectiveness in obtaining a long-term, maintenance-free final abandonment status of acid generating wastes is not determined. The underlying concepts of Ecological Engineering are to promote and utilize indigenous and/or tolerant biota to improve water quality on the tailings, and that leaving the tailings, by reducing infiltration of precipitation and through biological polishing. Although the overall approach is well established theoretically, the methods required to achieve promotion, establishment and utilization of indigenous plants have yet to be developed.

INCO Ltd, Sudbury Operations, assessed the Levack tailings site in 1984 specifically for its potential as a test site for developing Ecological Engineering methods. The site was found suitable, in fact ideal, as an area for applied research, due to the presence of various extreme waste management problems. In 1985, within the framework of the Reactive Acid Tailings Study (RATS) Program, INCO Ltd. - Sudbury Operations pursued further development of this project. The main emphasis in 1985 was to demonstrate that indigenous acid or alkaline tolerant vegetation could be introduced, established and promoted, since this was a primary requirement in the development and testing of the concepts of Ecological Engineering.

1.2. Objectives

The objectives of the 1985 program were:

1. to test in several areas on the Levack site, different introduction and expansion methods for species indigenous to acidic or alkaline waste site conditions;

2. to design and test waste water distribution systems suitable for Ecological Engineering, as well as evaluate background information on Levack hydrology;

3. to review oxygen measurements and instrumentation, and to ultimately design field tests on the effects of root zones on acid generation;

4. to investigate the possible role of filamentous green algae as biological polishing agents in seepages.

The results from the research efforts addressing objectives 1 and 2 are contained in the first three sections of this report. Objective 3 is addressed in connection with moss covers on tailings in the fourth section. The fifth section of the report gives the findings in of the seepage, i.e. objective four. The appendix contains data relevant for future work.

1.3. Site Description

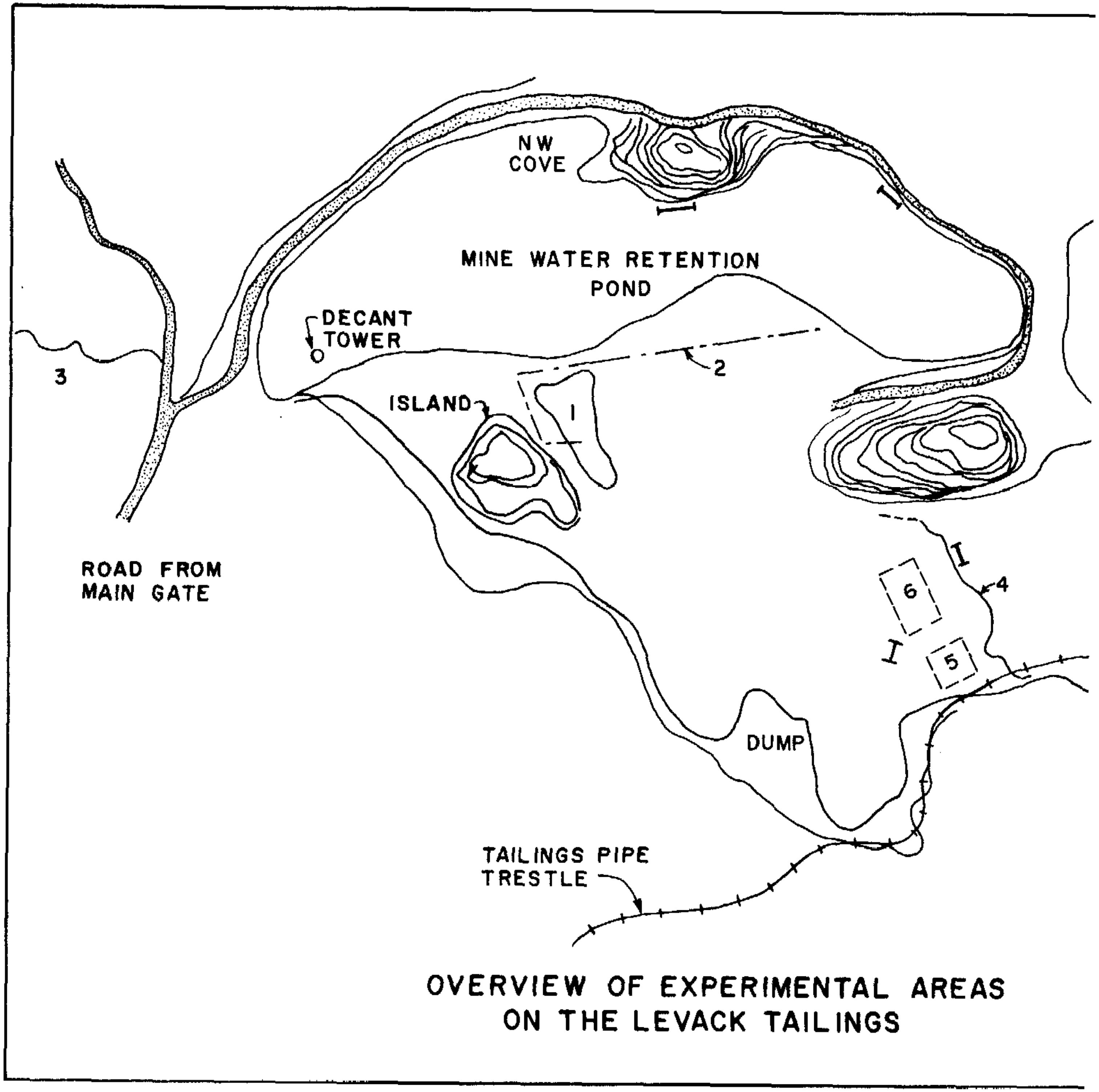
The Levack tailings area is situated in a basin which is generally typical of many in the Canadian Shield. These basins are characterized by forested, undulating terrain with shallow soils overlying Precambrian bedrock, with numerous bedrock outcrops. The basin experiences the typical climate for the entire northern Ontario region, with mild summers and cold winters. The climate is generally humid with approximately 950 mm of precipitation each year. Winters are characterized by extensive snow cover, which results in considerable runoff each spring. The average annual evaporation is approximately 500 mm, leaving a net water surplus of 450 mm. This surplus either runs off or infiltrates into the groundwater.

The Levack tailings area has an area of 45 ha and is ringed by four containment dams (Figure 1). Dams 1 and 3 are located at the southern extremity of the area and are in fact one continuous structure with a crest elevation of 1270 ft (INCO Drawing 47-656-C-2652, 1977). Dam 2 is located at the northern end of the tailings area and prevents the migration of tailings into Pike Lake. It is possible that seepage through Dam 2 is reaching the lake through underground channels. The crest elevation of this dam is 1264 ft (INCO Drawing 47-656-C-2509, 1976). Dams 1, 2 and 3 are lined on the upstream side by a synthetic membrane which erosion has exposed and which has failed in several places. Dam 4, located at the north-east corner of the tailings area, has a crest elevation of 1291 ft (INCO Drawing 47-656-C-2509, 1976). It was not clear from the on-site visits whether Dam 4 is lined with a synthetic membrane.

The surface of the tailings slopes along a line (P1 in Figure 1) of one percent. Farther down the tailings surface, the slope is reduced to approximately 0.2%. Such slopes are common in tailings areas. The surface characteristics are of several types. Moist alkaline areas covering a large fan extend all the way to the shores of a mine water retention pond (white area on Plate 1). Dark brown areas in Plate 1 consist of hard pyrrhotite cover and the light brown area is generally covered with loose pyritic tailings. The water body between dam 3 and dam 2 is acidic due to runoff and/or discharge from the tailings area, however, it was never used for tailings discharge. Three vegetated islands seen on the edges of dams 1 and 3 are elevated parts of the orignial landscape which were not covered with tailings. Traces of indigenous cattail stands can be seen in Plate 1 along the shores of the mine water retention pond.

Water enters the tailings area naturally through incident precipitation and runoff from the surroundings, particularly from the elevated southern edge of the tailings area. There are additional inputs from the mining operation which have produced the fan-shaped moist alkaline areas. Water exits the tailings via the decant structure located in the south end and via seepage pathways through the local bedrock or the dams. One seepage below dam 1 is examined in detail during this study.

Background information on the hydrology of the area is given in the Appendix along with an indication of the instrumentation required for a detailed area water balance assessment.



OVERVIEW OF EXPERIMENTAL AREAS
ON THE LEVACK TAILINGS

Plate 1. Aerial photograph of the Levack tailings site with the mine water retention pond in the foreground, the alkaline mine slimes on the lower right (white area) and the acidic pyrrhotite tailings on the upper left (brown area).

2. MATERIALS AND METHODS

2.1. Wetland Establishment and Expansion

2.1.1. Transplanting methods

Soil-to-soil method: Mature cattails (vegetative and those bearing fruit stalks) were dug at random from cattail stands and planted in 6 groups of 10 plants. Each group was a circular to elliptical array, 3-5 m in diameter. Four of the stands: 8, 10, 16 and 17, were transplanted in early July. Stands 6 and 7 were transplanted in late July. Their respective positions relative to the mine water retention pond are shown in Figure 2; a description of the various experimental cattail stands is given in Table 1.

Hydroponic Method: Cattails were dug from the bed of nearly 100% vegetative cattails in the NW cove of the mine water retention pond. The entire aerial (leafy) portion was cut off leaving the root crown, roots and any rhizomes, i.e. the underground stems which give rise to new juvenile plants. Eighteen cattail explants were placed about 0.3 m apart on a 6 m long, polyethylene net (2" mesh size) and laced into place with polyethylene line. Four such nets of explants were prepared. Two of them were installed along the shoreline of the minewater retention pond: one along the recently re-built rock dam and the second beneath the rock face on the west side of the pond (i.e. on top of the mine slime slurry). A third array was placed across the mine slimes, recently accumulated behind a boomerang dam which blocked up a small stream coursing across the pyrrhotite tailings. The fourth array was anchored in the lowest pool of the pre-bog acid creek (Plate 2). New shoot production will be recorded in all of the hydroponic cattail arrays next spring. The locations are indicated in Figure 2.

2.1.2. Cattail stand expansion: Cultivation of root zone around perimeter and in interior of stand

The perimeters of the stands were excavated in two manners (see Table 2). In the first, a total of about 15 cm of sediments was sequentially skimmed off in layers without disturbing the underlying sediments. In the second method, a 30 cm deep trench (=1 spade depth) was dug around the perimeter of the stand. The sediments were broken up and the trenches were either completely backfilled or backfilled to within 15 cm of the surface. The sediments around the perimeter of control stands remained untouched. In the spring (1986), the numbers of juvenile plants appearing around the perimeters of experimental and control stands will be compared.

An square plot (approximately 4 m x 4 m) in the centre of stand 21 was flush-cut and raked free of cut cattails and debris. The entire plot was cultivated by hand with a spade to a depth of 30-40 cm. If rhizomes were brought to the surface they were dug into the loosened sediments. Two adjacent plots of similar dimensions served as controls: one was flush-cut and the cattails were raked off, the other received no treatment. In the spring (1986), the numbers of new shoots emerging from the 3 plots will be compared. The locations of these excavation experiments are given in Figure 2 and referred to as cultivation experiments (Table 1).

Table 1. Cattail stand catalogue.

STAND #	USE
1	- control - cattail stand expansion expt.
2	- cattail rhizome depth determination
2A	- young cattail seedlings
3	- general utility stand, transplant source
4	- exptl. - cattail stand expansion expt.
5	- control - cattail stand expansion expt.
6	- cattail experimental transplant stand (n=10)
7	- " " " " (")
8	- " " " " (")
10	- " " " " (")
11	- control - cattail stand expansion expt.
12	- " " " " "
13	- general utility stand; transplant source
14	- exptl. - cattail stand expansion expt.
15A	- control expt. - cattail stand expansion expt.
16	- cattail experimental transplant stand (n=10)
17	- " " " " (")
18	- control - cattail stand expansion expt.
19	- exptl. - cattail stand expansion expt.
19A	- young cattail seedlings
20	- control - cattail stand expansion expt.
20A	- exptl. - cattail stand expansion expt.
21	- control; exptl. - cattail stand expansion expt. and cattail bed cultivation plots - controls and exptl.

Table 2. Cattail stand perimeter cultivation: Description of treatments.

STAND #	TREATMENT
1	- control; not cultivated
4	- experimental; dug and backfilled to 1/2 spade depth
5	- control; not cultivated
11	- " " "
12	- " " "
14	- experimental; dug and completely backfilled
15A	- 3 control sections; not cultivated - 2 sections cultivated and backfilled to half spade depth - 2 sections cultivated and backfilled completely
18	- control; not cultivated
19	- experimental; S side dug and completely backfilled; N side dug and half backfilled
20	- control; not cultivated

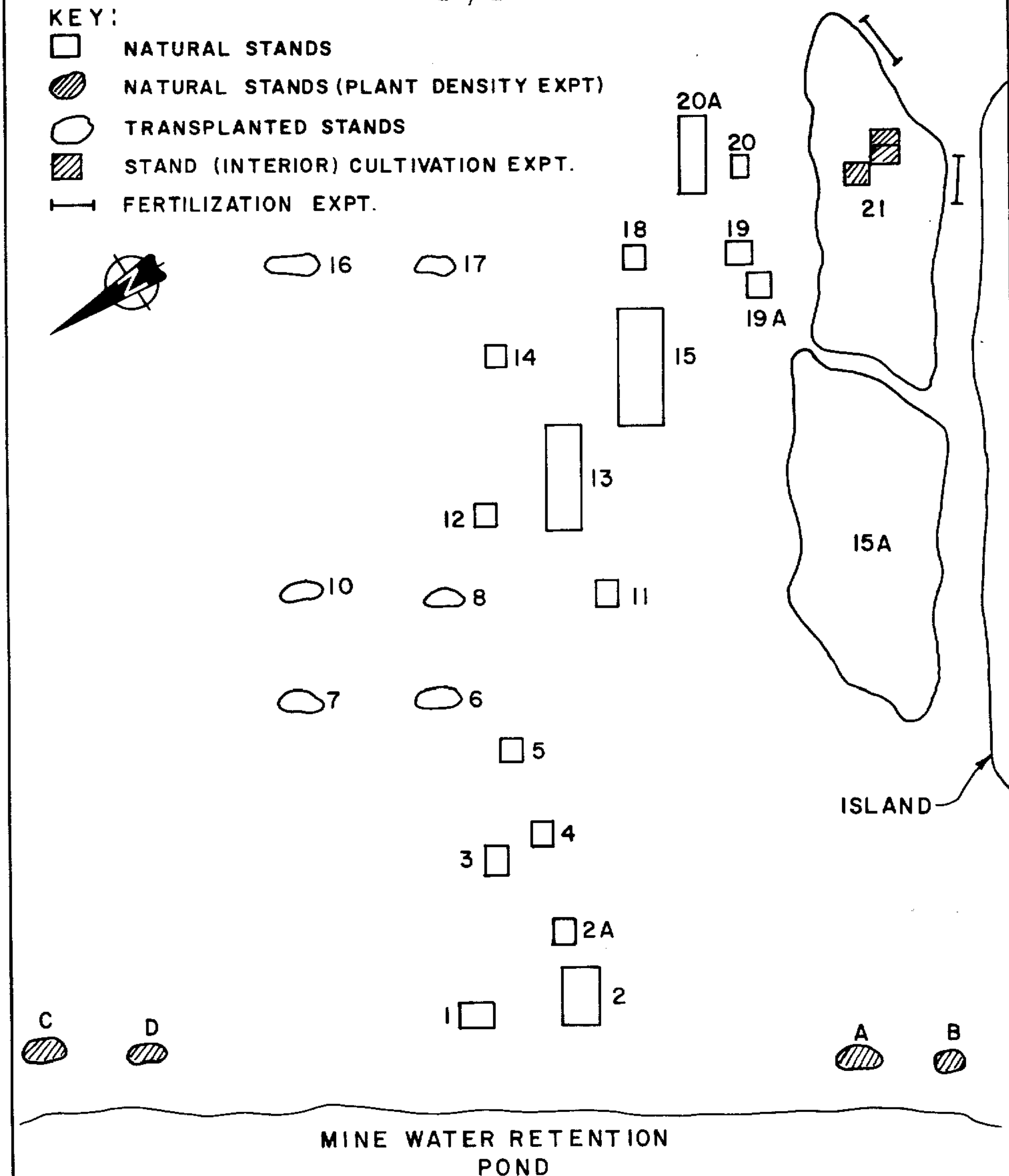


FIGURE 2

SCHEMATIC POSITIONS OF EXPERIMENTAL CATTAIL STANDS AT LEVACK (NOT TO SCALE)

Plate 2. Hydroponic cattail experiment in the pre-bog acid creek showing netting containing transplanted rhizomes. Acid cattail stand is in background.

2.1.3. Elemental analyses - leaves and leaf tips

Sampling locations: Cattail leaves and/or leaf tips were collected in September from the following locations: (1) an alkaline cattail stand (stand 15); (2) an acid cattail stand in the pre-bog acid creek; (3) a nearly 100% vegetative stand in the NW cove and the adjacent fertile stand; (4) a stand in a reportedly high nickel seep on Falconbridge property; and (5) a control site, a quarter mile off Hwy 144 on side road #65 to Rudder, Ontario.

Sampling methods: Vegetative leaves from non-fruit producing cattails and leaves growing around the inflorescence peduncle (fruit stalk) were collected. In addition, apical tips of leaves from the pre-bog acid creek and alkaline stand 15 were also harvested. The tip 5-15 cm of the former was black; the leaf termini were brown coloured in the latter stand. We hypothesized that leaf tip death was caused by high iron content in the xylem stream of the acid-grown cattails; total metal content was expected to be lower in the alkaline leaf tips, merely due to the pH effect on metal solubility in the alkaline mine slimes.

Sample preparation and analysis: The leaf collections were dried at room temperature and then in an oven (150^{o}C) for 30-60 min. They were ground in a Wiley mill outfitted with a 20 mesh screen. The ground samples were stored in sealed plastic bags. ICP analyses for 18 metals and phosphorus were conducted on the samples by the Central Process Technology Division of INCO, Sudbury Operations, Copper Cliff. Total C and total N (micro-kjeldahl) were conducted on the samples by personnel in the Department of Land Resourse Use and Soil Science, University of Guelph, Guelph, Ontario.

2.1.4. Mulching and fertilization of cattails and indigenous species on mine slimes

Two types of mulches were used to protect indigenous populations, i.e. mainly cattail (Typha) seedlings, sorel (Rumex), horsetail (Equisetum) and moss. Various amounts and thicknesses of straw and cotton tailings were spread by hand in several experimental plots located along the transect; these plots are indicated in Figure 3.

Two plots (4 m x 1 m) of young cattail seedlings 1-10 cm tall were fertilized in late July with 1 kg of either Scott's Grow Vegetables (18:24:6 N:P:K) or Scott's Grow Flowers (18:12:4 N:P:K). The locations of the plots are shown in Figure 2. The fertilizer was broadcast by hand and was not dug into the mine slimes. Control plots received no fertlizer. The qualitative effect of the fertilizers was monitored on the subsequent field trips.

2.1.5. pH determinations of mine slime sediments around cattail roots

At three randomly selected cattail roots, mine-slimes-lime profiles were excavated from the root rhizome zone. 60 ml of sediments were placed in a beaker to which distilled water was added to a volume of 220 ml. The slime-water slurry was stirred with a glass rod while the pH and conductivity were determined.

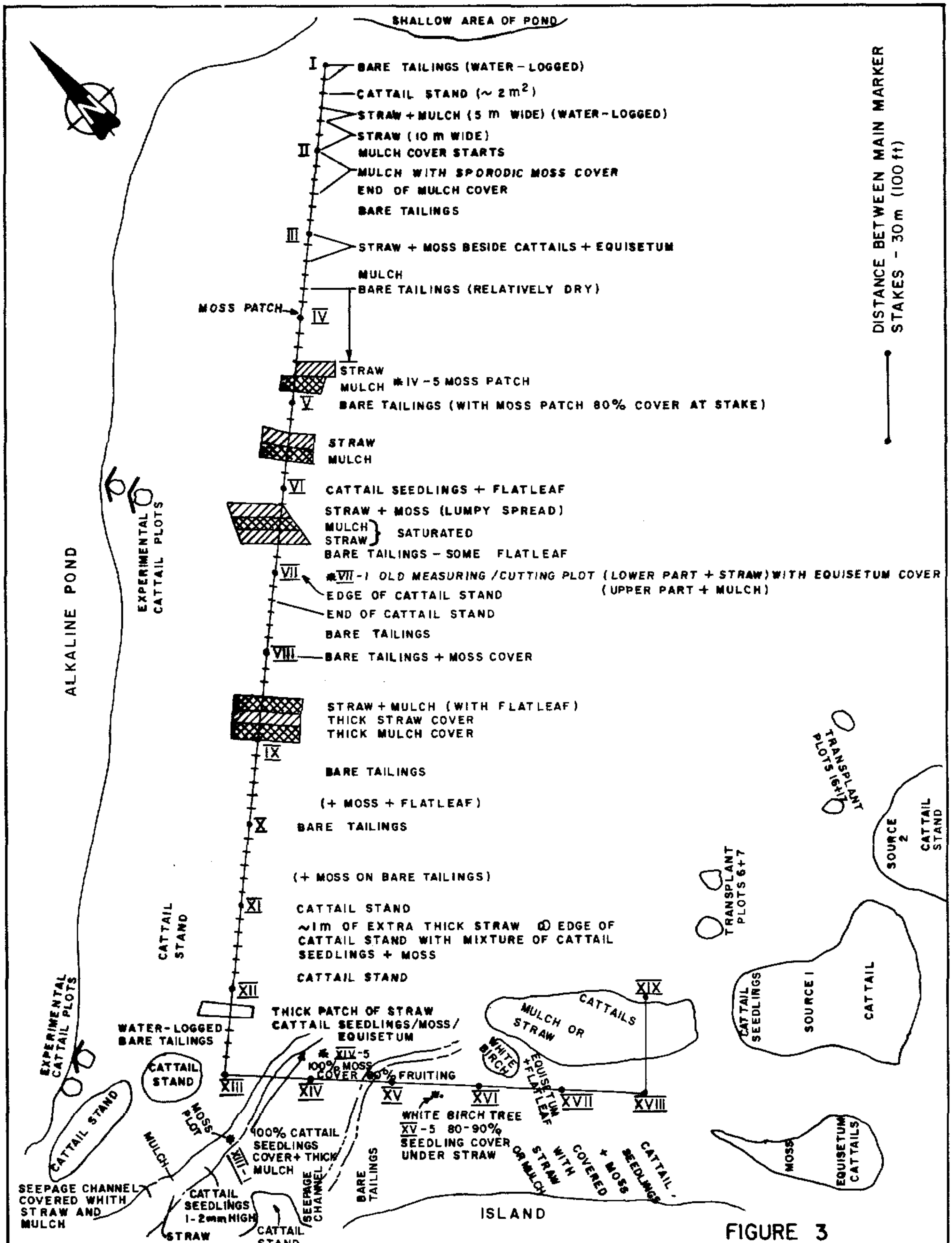


FIGURE 3

SCHEMATIC OVERVIEW OF BASELINE TRANSECT WITH MULCHING & CATTAIL FERTILIZATION EXPERIMENTS

2.2. Waste Water Distribution Systems

2.2.1. Requirements

Water distribution and irrigation systems are generally designed for water with low suspended solids. Applications for ecological engineering are different in that water with high suspended solids and corrosive chemical characteristics are to be distributed onto inaccessable areas or onto hard-to-reclaim material such as pyrrhotite and water-logged tailings areas. Ideally, the areas are to be moistened, but not flooded, by the system. This should be achieved with as little channelling as possible to prevent carst-type cracking of water-logged areas during dry spells, and to moisten oxidized pyrrhotite. In both cases, the aim of water distribution is to promote indigenous moss cover development. Second, and possibly equally important, the system should require little or no maintenance. Several methods were designed as test trials.

2.2.2. System design

System No.1 - Circular Spray: This system consisted of a pump drawing water directly from the tailings line, and an impact spray head (Figure 4). To improve the system, the portable pump is included to provide sufficient head and was to be used periodically to apply water over the designated area via the sprayhead. The sprayhead was elevated above the surface of the tailings by approximately 1 m. It was recommended that 5 cm of water be applied at each watering.

System No.2 - Linear Spray: This system consisted of a gravity line taken from a tap in the tailings line through a throttle valve to distribute water via perforated pipes (Figure 5). This is similar to the perforated pipe system already installed by INCO in early July. The linear spray system was designed to supply water to the surface continuously.

System No.3 - Perforated Pipe System: This is an overland flow system which provides a continuous supply of water. The objective was to distribute the water over a long distance and to get a more even flow. A piece of derelict tailings pipe was cut, capped at the ends and holes drilled as shown in the drawing (Figure 6) and laid approximately level for a distance of 50 feet. A flexible hose was attached to one end of the pipe so that water overflowed through the holes onto the tailings.

System No.4 - Flooded Furrows System: This system was designed for use on the disked areas of pyrrhotite in order to identify any benefits that might be gained from capillary action in this material. Several furrows were excavated in the disked area to a depth of 6 to 12 inches and a similar width (Figure 7). The furrows were cut across the slope of the tailings so that each furrow was approximately the same elevation along its entire length. These furrows were to be flooded periodically by the application of water from a flexible hose located at one end of each furrow. Once all furrows were full, the filling was stopped and the water allowed to sit, and either infiltrate or be taken up by capillary action into the surface nearby. Three furrows were excavated on 6 foot centres over a distance of approximately 25 feet. In measuring the effectiveness of this system, the length of time in

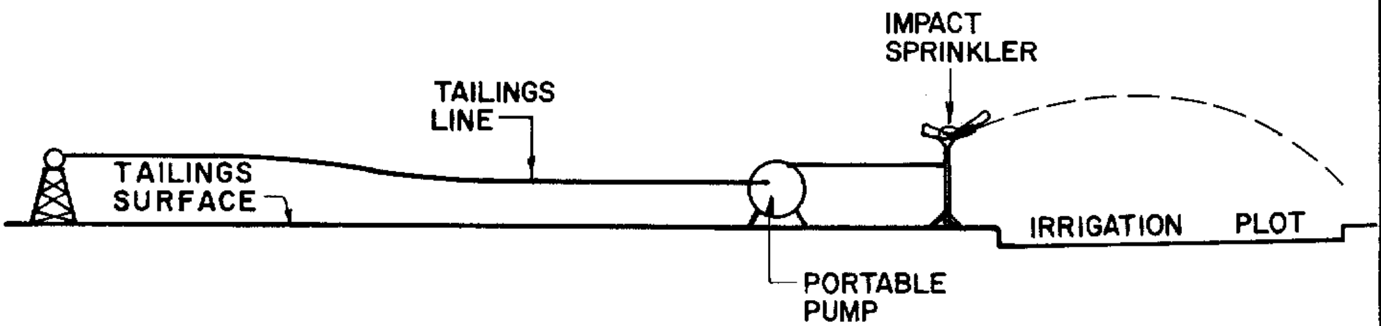


FIGURE 4

SYSTEM I: CIRCULAR SPRAY

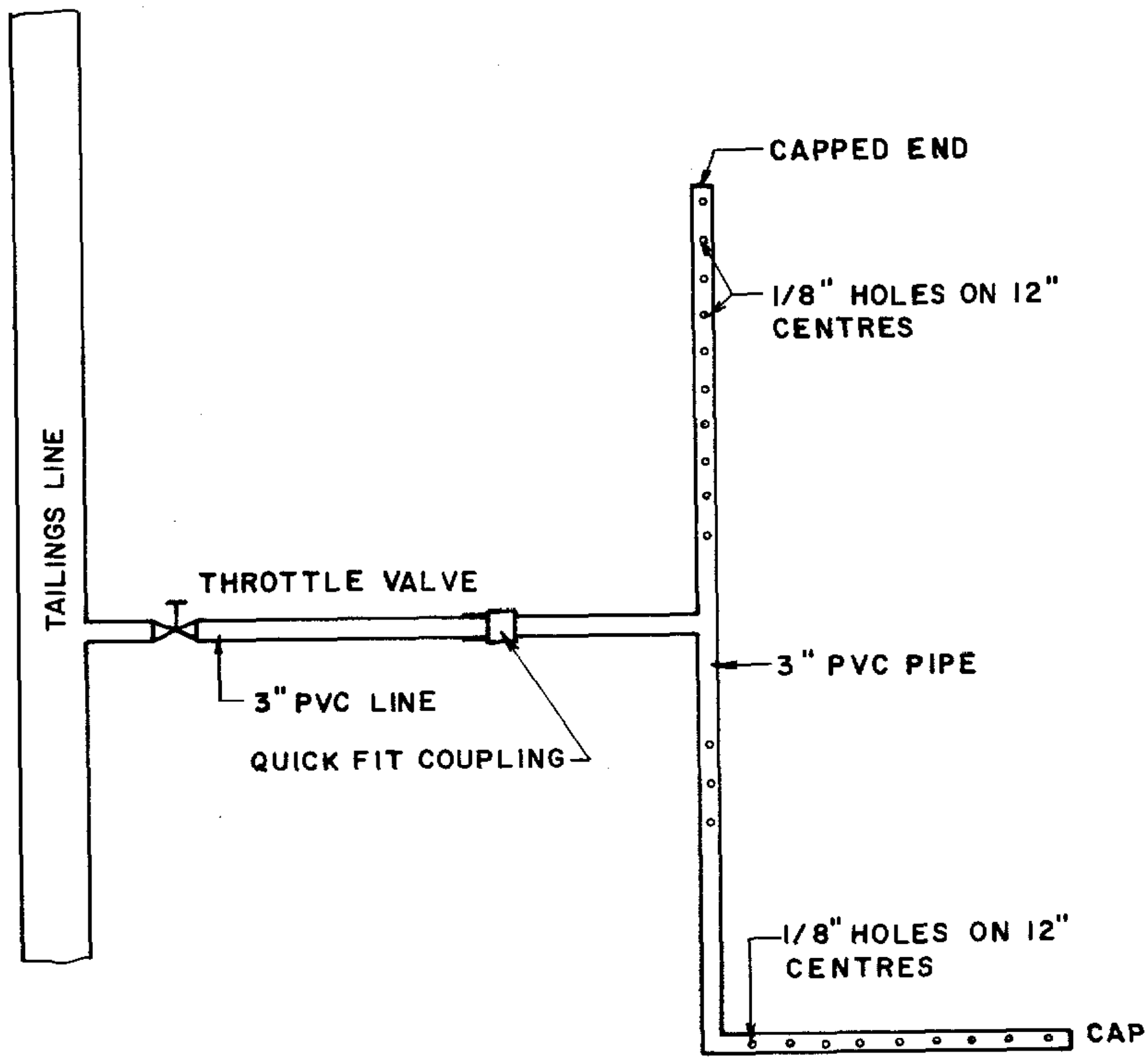
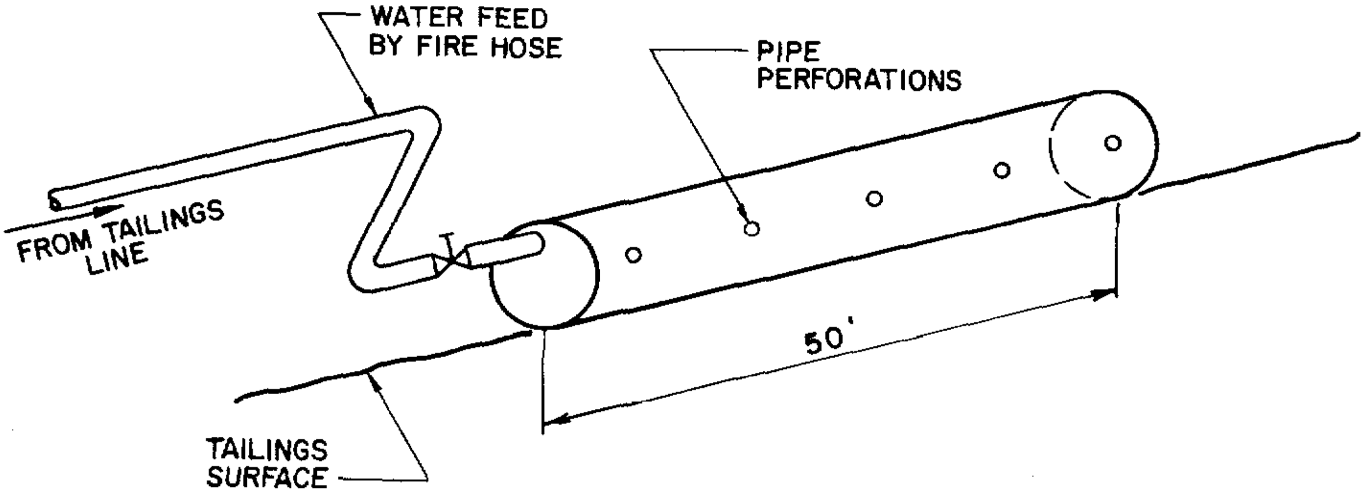
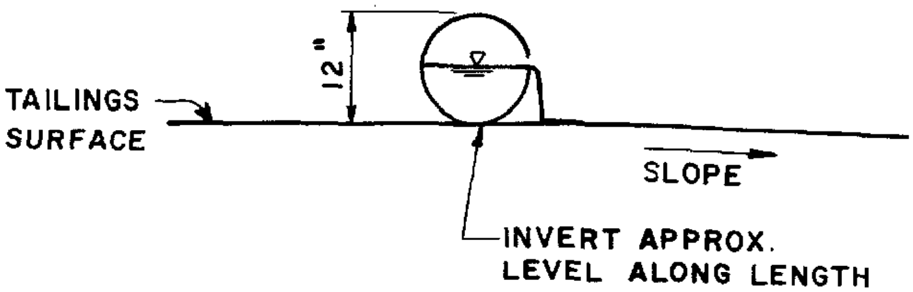


FIGURE 5

SYSTEM 2: LINEAR SPRAY



ELEVATION



SECTION

FIGURE 6

SYSTEM 3: PERFORATED PIPE SYSTEM

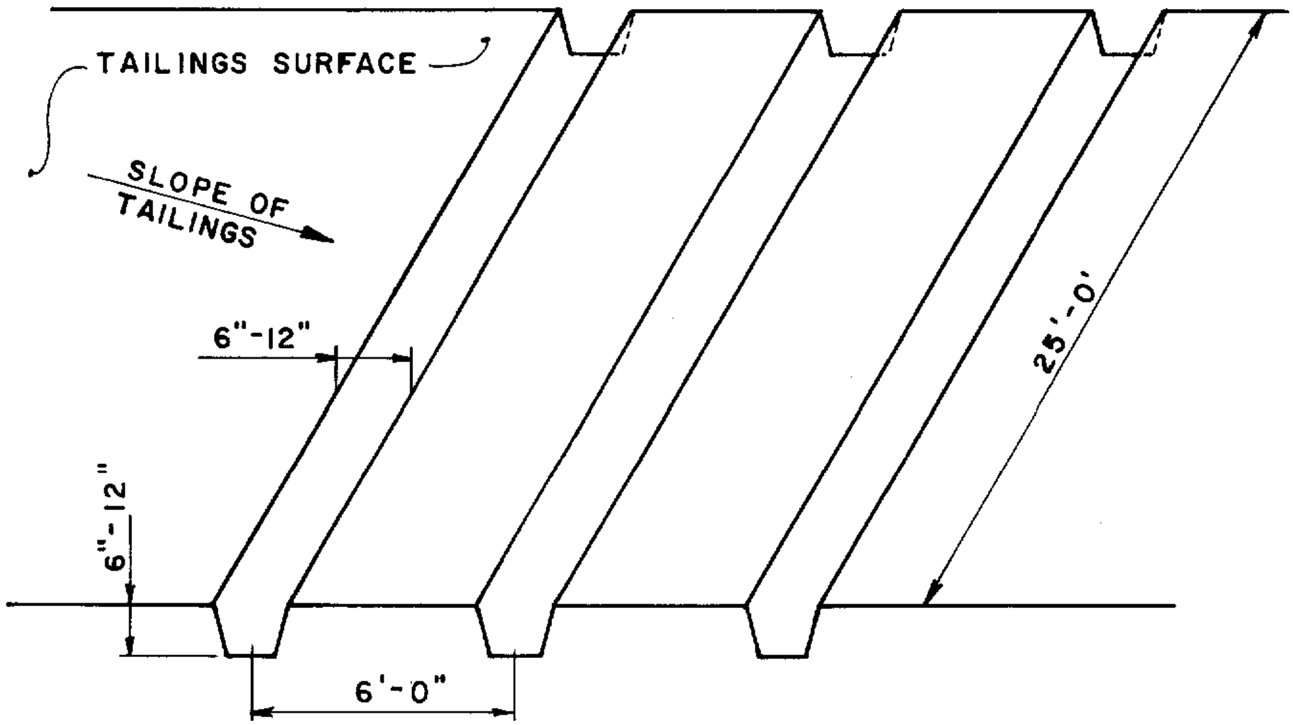


FIGURE 7

SYSTEM 4: FLOODED FURROW SYSTEM

which the water remained in the furrows was considered.

System No.5 - Stream Distribution System: The design of this system was intended to provide moisture to a wide area by a series of dams on the stream emanating from the discharge of the tailings pipeline. These dams were constructed by rolling wet pyrrhotite tailings inside a tube formed from a polyethylene sheet. The tubes were placed in the drainage channels on the surface of the tailings. Several were placed in such a way that the channel was forced to change direction, thereby wetting a large surface area (Figure 8).

2.3. Wetland Species Selection for Extreme Conditions

2.3.1. Extreme alkaline conditions: Transplant squares

Confinements of 2 x 2 m, made out of two-by-fours, were sunk into lime sediments and into areas with alkaline precipitates originating from treatment system. The purpose of these confinements was to hold the transplanted species in place for observations on growth and establishment. Phragmites, Juncus, Carex and Potamogeton were transplanted from the Falconbridge Conservation Area into these confinements.

Chara vulgaris was collected from LaCloche Island in May and July, 1985, and transported to Levack in a cooler. The algae were placed in an "onion sack" container (50 cm X 20 cm) and then installed along the shores of Dam 1 in the mine water retention pond. Each sack of Chara was attached to a fluorescent-tagged buoy. Health and growth of the Chara was checked June and in September.

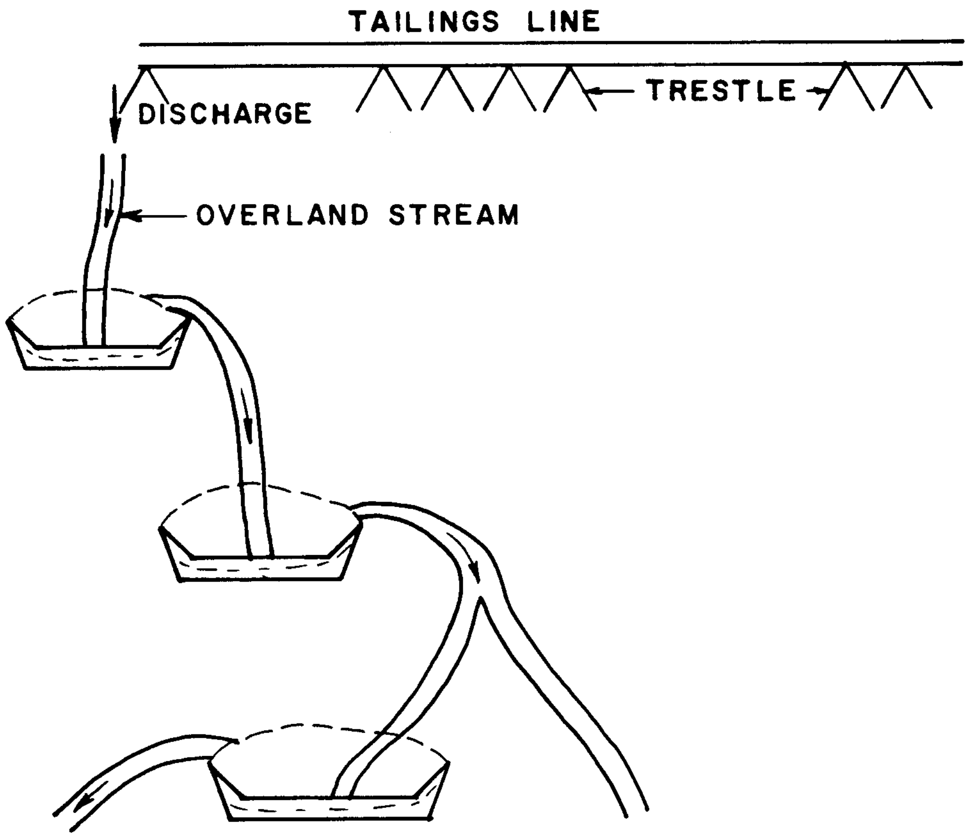
2.3.2. Extreme acid conditions: Dam sequence in the pre-bog acid creek

Dam installations: At three locations across the acid creek, earthen dams were installed by INCO Agriculture personnel in order to slow the water movement and to create small experimental ponds for studies on aquatic plant growth. The first dam was installed near the mine water pipe trestle at the head of the creek; the second, midway along the length of the creek and the third, just below the natural stand of cattails. The dams, as shown in Figure 9, have been successful in holding back water and three small ponds in the acid creek have been formed.

The pond at the foot of the creek, which contains several small cattail stands, has been seeded with explants of the acidophilic aquatic moss. In addition, a hydroponic cattail transplant experiment (see section on cattails) was set up in this pond to test (1) the effect of acid water on the over-wintering of hydroponically-grown cattails; and (2) the chemical resistence of the netting used to hold the cattails in the acidic water.

2.3.3. Permanent transect: Catalogue of indigenous species

In order to monitor changes in the vegetative cover on the Levack tailings which we anticipated will occur as changes in water flow pattern(s) are



LOCATIONS AND EXTENT DETERMINED
IN THE FIELD.

FIGURE 8

SYSTEM 5: STREAM DISTRIBUTION SYSTEM

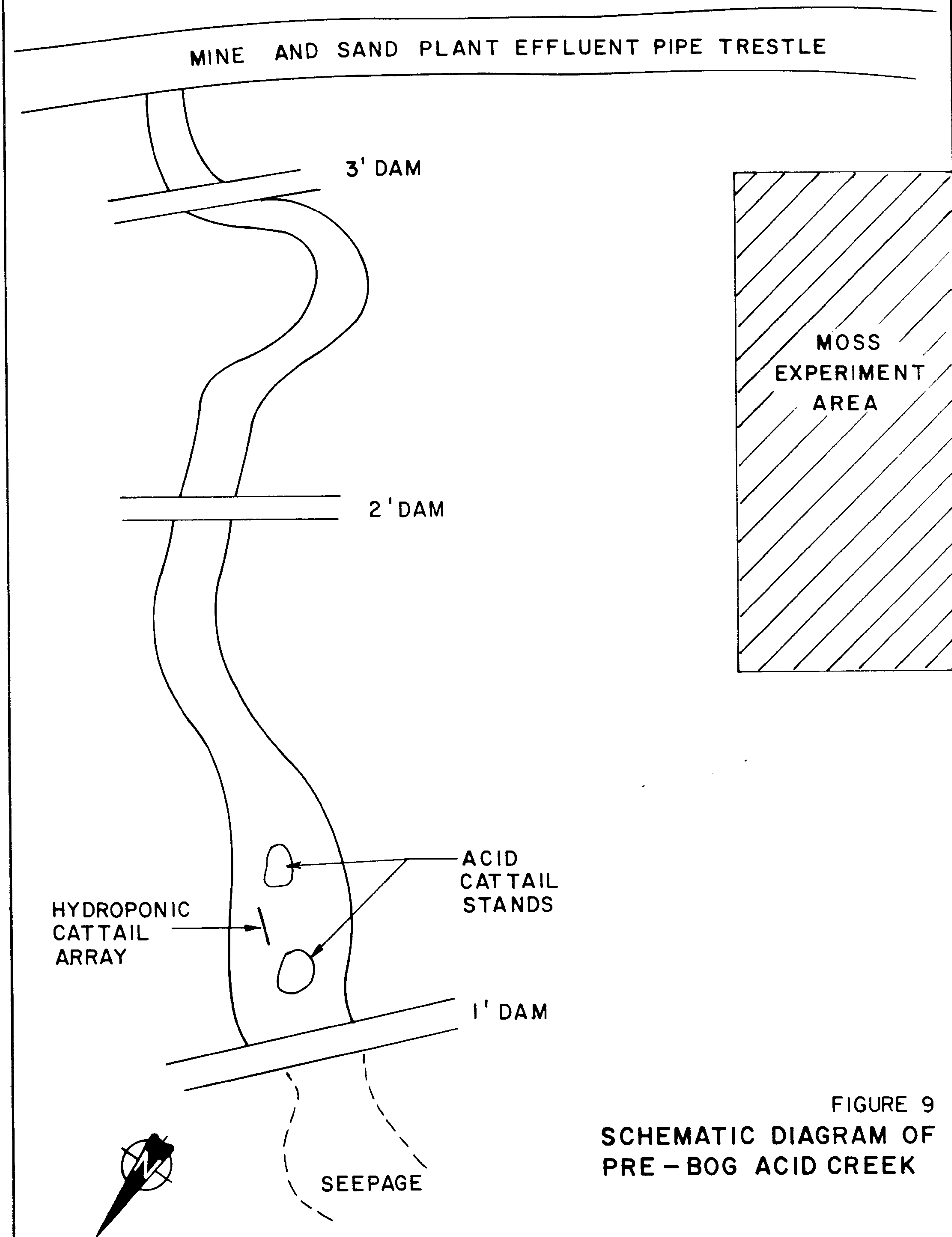


FIGURE 9

SCHEMATIC DIAGRAM OF PRE – BOG ACID CREEK

implemented, the classical ecological plant assessment technique -- that of setting up a permanent "transect line" and monitoring changes in the flora which occur over time in the vicinity, i.e. within 1 m^2 quadrats, of the line -- was installed.

During the first field trip in June, a 300 m transect was measured out along the south beach of the mine water retention pond, extending from the large cattail stand on the northeast side of the tailings beach to the southwest side, and a further 180 m transect was set up south- westward between the cattail stands and the island to the west. The transect (see Figure 3) was set up so that most of it was parallel to the shore of the mine water retention pond. Cobbles, each 20-30 cm in diameter, were placed every 10 m along the line and numbered stakes were driven into the sediment at 60 m intervals.

Along these transects, sampling quadrats were set up where indigenous species were recorded to document establishment and growth/death over the season along with the effects of the various treatments used. The first 1 m^2 quadrat estimates of plant cover within the 1 m^2 were made in July. The second and third monitoring of the transect occurred in August and September. In all cases, the percentage of the transect occupied by various kinds of plants, mulch, dead leaves, etc., including, of course, bare tailings, were made. Within any one quadrat, the percentage of cover may frequently exceed 100% due to overlapping, e.g., straw cover on mosses and young cattail seedlings, etc. The percentages given are, therefore, merely a rough estimate of plant type abundance. What will become noticeable, over the next few years, is the long-term changes which occur along the transect as the Levack tailings are made more amenable to plant colonization. The vegetation data collected over the summer from the permanent transect quadrats are summarized in the appendix.

2.4. Mosses

2.4.1. Identification of mosses

Mosses were collected from various locations on the Levack site as well as from tailings areas on the properties of Falconbridge and Rio Algom Ltd. The collections were air-dried at room temperature, packaged and sent to Ms. C. Manville, a professional moss taxonomist, for identification. Voucher specimens will be deposited an the National Museum of Canada, Ottawa, on completion of the project.

2.4.2. Acidophilic and alkaline moss transplant experiments on Levack site

For the acidophilic moss, Leptobryum pyriforme, collected from acidic mine slimes at Falconbridge, two types of transplanting techniques were used:

(1) clumps of mine slimes bearing the thin cover of the moss (the protonema stage) were dug into the surface of loosely broken up pyrrhotite or mine slimes;

(2) the moss with underlying mine slime was broken into small pieces and distributed over the surface of the shale-like pyrrhotite. Then using a circular motion with palm of the hand, the moss was "slurried" into the pyrrhotite. It should be noted that a slight drizzle was falling on that occasion and the moisture facilitated the surficial mixing process.

Similar techniques were used to seed the alkaline moss which had been collected from the alkaline mine slimes near the waste rock dump site to the south of the experimental moss transplant sites.

Prior to planting the mosses, some of the pyrrhotite and mine slime plots were amended with either sand or a sandy topsoil to test the effect of such additions on moss growth. Control plots received no amendments. The locations of these plots are shown in Figure 10.

2.4.3. Fertilization and physical amendment of mine slimes - enhancement of indigenous alkaline mosses

A sparse cover of indigenous alkaline moss covered the mine slimes in an area to the NE of the L-shaped irrigation system. Six plots (approx. 2 m x 2 m) were delineated in an experiment to determine the effect of (1) physical amendments, such as sand, sandy topsoil and straw on alkaline moss growth, and (2) the effect of 3 kinds of fertilizers on moss growth.

The physical amendments were raked into surface 2-3 cm of the mine slimes with a hoeing action and then smoothed out. The fertilizers (300 g each) were broadcast over the surface of the mine slimes and they were not dug into the sediments. The three fertilizers supplied by Inco, were Nutrite (5:20:20 N:P:K), Urea (46:0:0 N:P:K) and NH_4NO_3 (34:0:0 N:P:K). A control plot for the physical amendment received a surface cultivation with a comb rake; the control plot for the fertilizer treatments was left undisturbed.

2.4.4. Greenhouse experiments

The greenhouse moss experiments were designed to test the effects of various drainage conditions on moss growth. Moss samples were collected in late June from the Copper Cliff Rubber Dump. Clumps of moss and associated substrate (approximately 50 by 30 cm by 10 cm deep) were dug up and placed in wooden flats; a total of seven samples were taken. One flat of the alkaline moss from the mine slimes of the Levack tailings was also collected. In the INCO greenhouse, the profile of the moss and substrate layers was described, and pH and conductivity measured.

Three drainage treatments were set up for each of the samples. The three treatments were: 1) normal drainage (producing moisture fluctuations); 2) no drainage (creating constant saturation); and 3) on-demand drainage (providing an intermediate conditions between saturation and drought).

Each flat of moss was divided into three subsamples to be used for each of the drainage treatments. The normal drainage condition was set up by placing the moss in an unlined wooden tray; the moss and soil were watered and any excess water was allowed to drain out of the tray. Watering was done twice a week; this treatment provided a range of moisture conditions from very wet

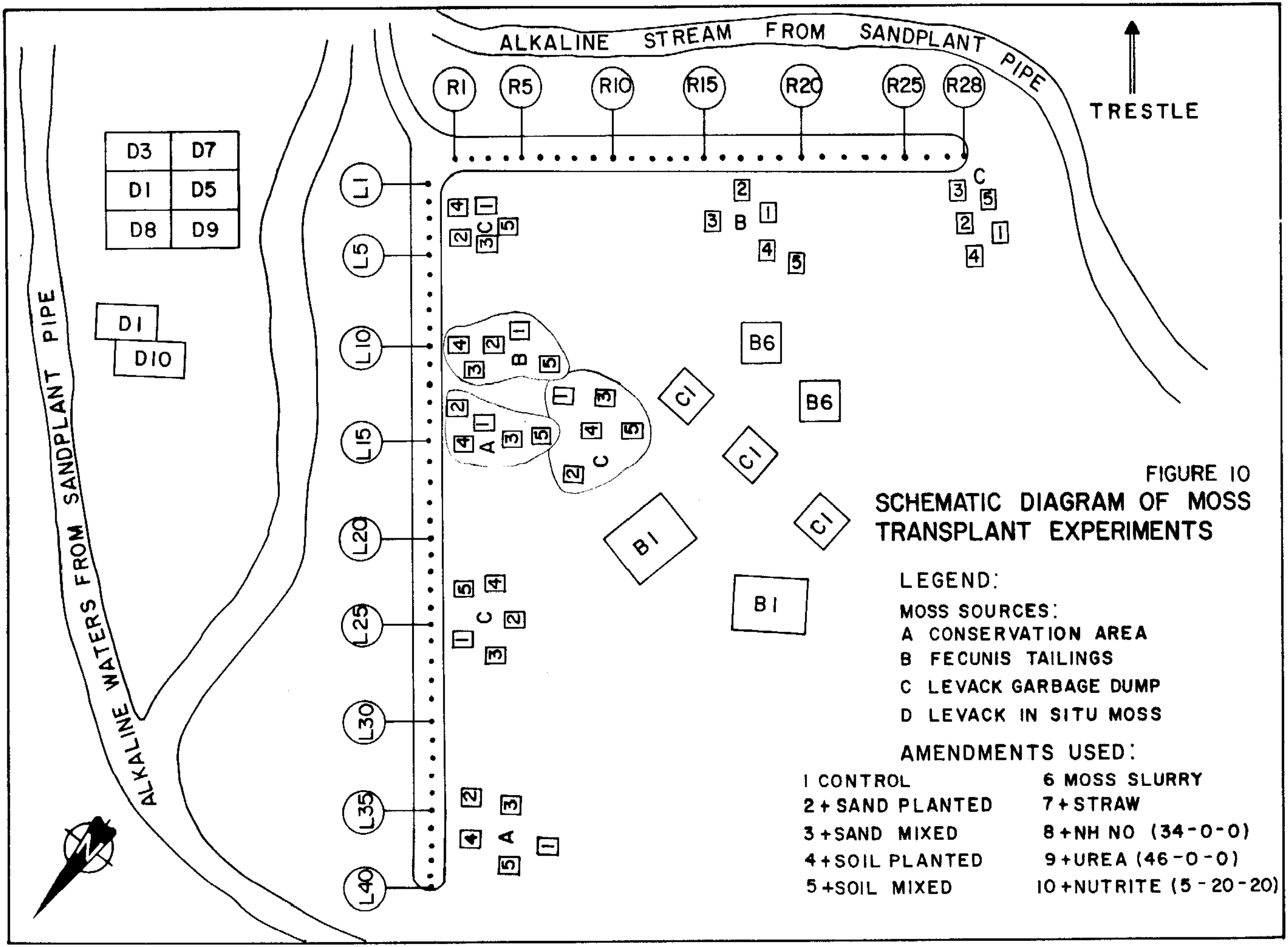


FIGURE 10

SCHEMATIC DIAGRAM OF MOSS TRANSPLANT EXPERIMENTS

LEGEND:

MOSS SOURCES:

A CONSERVATION AREA
B FECUNIS TAILINGS
C LEVACK GARBAGE DUMP
D LEVACK IN SITU MOSS

AMENDMENTS USED:

1 CONTROL	6 MOSS SLURRY
2 + SAND PLANTED	7 + STRAW
3 + SAND MIXED	8 + NH NO (34-0-0)
4 + SOIL PLANTED	9 + UREA (46-0-0)
5 + SOIL MIXED	10 + NUTRITE (5-20-20)

(after watering) to very dry (between waterings). In the second treatment, drainage from the trays was prevented by lining the wooden tray with a plastic liner, then placing the moss sample on top of the liner. Water was added until the moss and soil were saturated and a layer of water (about 5 cm deep) was kept on the bottom to maintain the saturated conditions. The third treatment provided an intermediate moisture situation. Plastic flower pots (4-inch diameter) were lined with paper towel and half-filled with perlite; the moss sample was placed on top of the perlite layer. Three replicate pots were set up for each of the moss collections, and placed in a plastic-lined wooden tray. Water was added until it drained onto the plastic liner. A layer of water (2 to 3 cm) was kept in the tray to provide water to the pots as required, thus keeping the mosses moist but preventing the fluctuations in moisture levels present in the other two treatments.

The experiment was set up in late June and continued until the end of October. Over the 12-week period from August 1 to October 24, the conditions (colour, mat thickness, number of sporophytes, etc.) of each moss treatment were described at weekly intervals and moss cuttings collected for moss growth quantification.

A second set of experiments were set up in the greenhouse to examine the effect of various tailings amendments on the growth of indigenous mosses. Mine slimes and pyrrhotite tailings from Levack were amended with sand or clay, or left unamended. The growth of mosses from Falconbridge and Levack were tested; the results in the greenhouse were similar to those reported from the field tests.

2.5. Seepages from Tailings: the Seepage Creek

2.5.1. Site description

Sampling stations were set up at 50 m intervals along the seepage creek (Figure 11). Dates for the collection of water, sediment and/or biota samples were: July 13, August 13, September 12 and November 10, 1985. Biota samples were preserved with Lugols fixative (approximately 1%). Temperature and flow rate measurements were also made. The general physical characteristics of each station were described.

2.5.2. Analysis of biota, water and precipitate

Water samples were taken to INCO for analysis within 24 hours of their collection and were maintained either on ice or in a refrigerator during the interim period. Samples of biota and sediments were taken to Boojum Research in Toronto where they were prepared for microscopic examination and/or chemical analysis. An attempt was made to remove iron precipitate from some of the filamentous algal samples before submitting them for chemical analysis. Precipitate from the creek was dried and pulverized with a mortar and pestle prior to submission for analysis. Chemical analyses were performed using ICP and AA spectroscopy by the Central Process Technology Division of INCO, Sudbury Operations, Copper Cliff.

3.0. RESULTS AND DISCUSSION

3.1. Wetland Establishment and Expansion

3.1.1. Cattail stand expansion, transplanting and seedling survival

Cattail stand expansion: One of the ecological engineering objectives for wetland establishment on the Levack tailings is the development of methods to increase the present population of cattails. This objective implies both the expansion of existing cattail stands and the installation of new beds where none currently exist (via transplanting techniques or direct seeding). With regard to cattail stand expansion, we observed that a few of the cattail stands had a large number of juvenile plants, i.e. ranging in size from those which had barely pierced the sediment surface to plants < 30 cm tall. The majority of large and small stands, however, had comparatively few juveniles.

Referring to the sketch in Figure 2, stand 2, close to the water, had more juveniles than stands 15A & 21, for example ---or even stand 4. Regardless of the proximity of the cattail stands to the shoreline, however, it seemed clear that stands were not expanding if no, or very few, juvenile shoots were being produced. Thus, it seemed reasonable to develop an empirical method whereby the bed expansion potential could be evaluated, that is, a measurement of the number of new individual(s) produced per mature individual present in the stand. This relationship was expressed as a ratio, i.e. the number of new plants divided by the number of mature ones, and this ratio has been employed in many of the experiments which were set up on the mine slimes.

Juvenile-to-mature plant ratios were computed for 7 small cattail stands which were employed in cattail stand expansion experiments. In Table 3, the ratios are computed on the basis of all individuals in the stand and yields an average value of 0.2 or about 1 juvenile to 5 mature plants. In Table 3, the same ratio is computed for the same 7 beds by counting just those individuals around the perimeter of the bed. In this case, a higher ratio of 0.3 was determined, or about 1 juvenile for every three adult plants.

The seven beds were mapped for the locations of all of the plants (dead or alive; maps not included in this report) and it was obvious that the great percentage of juveniles occurred around the stand perimeter. Therefore, the higher ratio computed from a count of just juveniles and mature individuals located around the perimeter is understandable.

As noted above, it seemed obvious that in order for existing cattail stands on Levack mine slimes to expand, the mature individuals had to be producing juvenile shoots; stand 2 had numerous juveniles while stands 15A and 21 had relatively few. While juvenile shoots emerged some distance (10 to < 50 cm) from the parent plant in stand 2, new shoots frequently came up "cheek to jowl" along side the parent in stand 15A and 21 (and elsewhere---see photographs in Plate 3).

These latter observations lead to the comparative study of rhizome depth and juvenile shoot production in stands 2, 15A and 21. The data are shown in the bar graph in Figure 12. It is evident that stand 2, which had a juvenile-to-

Plate 3a. Young cattails emerging through the mine slimes alongside the dead parent cattails. Note this route of rhizome growth may represent the easiest way to the surface where no new penetration of the compacted layers of mine slimes is required.

Plate 3b. Horizontal cattail rhizome on right terminated by a contorted juvenile shoot (at arrow). Two arrows on left point to dead juvenile shoots which were apparently unable to penetrate the compacted layers of mine slimes. Parent cattail is behind white stake.

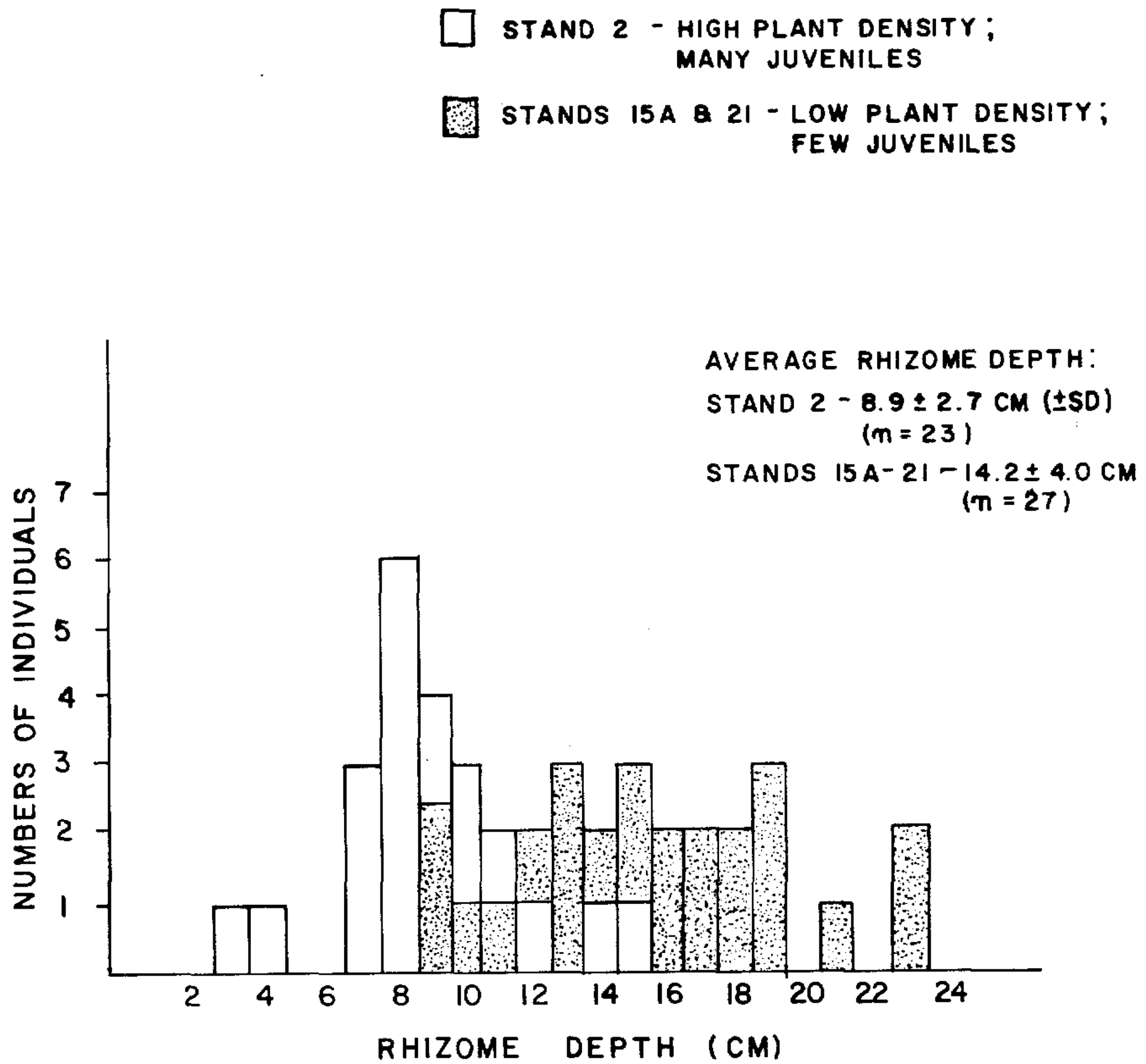


FIGURE 12
APPARENT CATTAIL STAND EXPANSION POTENTIAL AND RHIZOME DEPTH

Table 3. Cattail stand expansion experiment: Calculation of ratio of juvenile to mature plants.

	Total # plants within stands						Total # plants around stands		
Stand #	Mature Veg.	Mature Fruit.	Total	Juvenile (<30cm)	Dead	Ratio	Mature Veg.& Fruit.	Juvenile (<30cm)	Ratio
1	19	14	33	7	27	0.2	26	6	0.2
2	21	7	28	0	12	0	21	0	0
11	56	9	65	26	0	0.4	29	15	0.5
12	31	9	40	14	28	0.4	29	12	0.4
14	13	0	13	2	7	0.2	12	2	0.2
18	35	5	40	10	25	0.3	24	7	0.3
19	35	15	50	8	71	0.2	29	8	0.3
				Average		0.2		Average	0.3

mature plant ratio of 0.6, calculated for individuals at the perimeter of the bed only (raw data not shown), had a shallow rhizome depth. For the other two stands (Table 3), the juvenile-to-mature plant ratio was 0.08 with a corresponding shift in rhizome position toward a greater depth. The average rhizome depth in stand 2 was 8.9 + 2.7 cm (SD) while that in 15A and 21 was 14.2 + 4.0 cm (SD).

During excavations to determine rhizome depths, we observed that layers of very compacted slimes and lime were encountered which gave a noticeable "resistence" to the spade and hand trowel. In many cases, we noted that the cattail rhizome with aborted shoot primordia lay just underneath the compacted sediment layers. By analogy, we concluded that if we encountered resistence while digging downward from the surface, surely young cattail shoots would be encountering similar resistence while trying to grow up toward the sediment surface through this compacted layer.

As noted in the Materials & Methods, several techniques of trenching around the perimeter of cattail stands were employed (Table 2). In addition, we cultivated a large plot of flush-cut cattails within stand 21 (see Figure 2 for the location of this experimental plot). The results of the excavating experiments will be evaluated in spring, 1986, when a comparison of the numbers of juvenile plants in the control and experimental plots is made.

Table 4 gives the initial juvenile-to-mature cattail plant ratios around the perimeters of the contol and experimental (=excavated) stands (or portions thereof) (see Plates 4 and 5). In spring and summer of 1986, these beds will be monitored to determine whether these initial ratios have changed in the control and experimental stands. See also Table 1 and 2 which describe the stands receiving the experimental excavations.

On excavating around the mature cattails in the latter stands, root-rhizome pH measurements were carried out. Table 5 gives the pH's of the mine slimes-limes around the roots and rhizomes of the cattails. They range from 8.5 to 9.9 with an average of 9.2. Of particular interest was a case in which the pH of the mine slimes in the vicinity of the parent plant was 8.5, while the pH, just 30 cm away, around the roots issuing from the rhizome of the parent was 4.6. The latter roots were actually growing into some fine pyrrhotite granules.

Table 4. Cattail stand perimeter cultivation experiments: Initial number of mature plants and new emergent shoots along perimeter of stand.

Stand Number	Control or Experimental	Total # mature plants around stand perimeter (Veg. and Fruit.)	Total # new emergent shoots around perimeter	Ratio of new shoots mature plants
1	Con.	26	6	0.23
4	Expt.	21	0	0
11	Con.	29	15	0.51
12	Con.	29	12	0.41
14	Expt.	12	2	0.17
15A	Con.	23	1	0.04
15A	Expt.	11	0	0
15A	Expt.	9	0	0
15A	Con.	5	0	0
15A	Expt.	9	1	0.11
15A	Expt.	6	1	0.16
15A	Con.	9	0	0
18	Con.	24	7	0.29
19	Expt.	29	8	0.28
20A	Expt.	47	5	0.11
21	Con.	12	1	0.08
21	Expt.	9	1	0.11
21	Expt.	14	5	0.35
21	Con.	14	1	0.07
21	Expt.	27	0	0

Plate 4. Experimental stand for cattail expansion experiment. Perimeter of stand was excavated to a depth of 30 cm and completely back-filled (left side) or half back-filled (right side).

Plate 5. Control stand for cattail expansion experiments. Note juvenile plants in centre foreground emerging beside stalks of dead parent.

Table 5. pH and conductivity of mine slimes-lime sediments in the root-rhizome zone of cattails.

Cattail Stand	Root-Rhizome Depth (cm)	pH	Conductivity $umhos.cm^{-2}$
4	26	9.9	500
11	18 (23)	9.3 (9.7)	500
19	27	8.5	550
		4.6*	800

* The rhizome from one parent root crown had its own roots penetrating a layer of pyrrhotite. The latter roots were about 30 cm from the parent plant.

It should be noted that cattails growing on the alkaline mine slimes can be transplanted into the acid creek where the pH is 2.5 to 3.5. Although the parent plant succumbs to this drastic pH change, young shoots emerge from the root crown or from short rhizomes. It should also be noted that many of the parent plants died after being transplanted to new sites on the mine slimes from mature stands growing on the same substrata. However, juveniles produced by these plants survived. It was noticed that the rhizomes of cattails growing in stands with a low expansion potential frequently bore one or more dead juvenile shoots or frequently, a growing juvenile which was highly contorted and mis-shapen (see Plate 4).

Seedling survival: During the 9-14 July field trip, two small plots of young cattails were fertilized with two kinds of Scott's garden fertilizer (see Materials and Methods); the location of the plots is shown in Figure 2 and are on the island side of the mature cattail stand 21. Adjacent plots received no fertilizer treatment. No evidence of a positive benefit of the fertilizers could be visually detected after 33 days. However, after 60 days, young stands in the treated plots showed good green colour and ranged in height from 2.5 to 15 cm. In adjacent control plots, all the plants were dead. The fertilizer contained NO_3, PO_4 and K and it is well known that the tailings are deficient in phosphorus.

Seedlings: Greenhouse and laboratory: Cattail seedlings which were flourishing on the Levack mine slimes in July were carefully dug up and brought to the INCO greenhouse and to Boojum Research in Toronto, to grow under more controlled conditions. In spite of careful attention to water requirements, the young seedlings on the mine slimes in both the INCO greenhouse and the Boojum lab slowly died---for reasons which we cannot explain at this time. It should be noted however, that the vast majority of young seedlings on the tailings also perished by the end of the summer! There were, however, 3 notable exceptions: 1) isolated pockets of seedlings, well removed from established cattail stands, which were healthy into September and which were marked for observation in 1986 (Table 1 - stands 2A and 19A);

2) the expanding delta of mine slimes extending out into the mine water retention pond has a very healthy population of young seedlings and their fate in 1986 will also be monitored; 3) the 2 plots of seedlings which received the fertilizer treatments.

Transplanting soil-to-soil - alkaline mine slimes: A total of 6 new stands of cattails were started by transplanting plants from established beds (10 plants per new stand (Plate 6); see Figure 1 showing locations of transplanted beds 6, 7, 8, 10, 16 and 17). By the time of the last field trip in September, nearly 60 days after transplanting, only one of the initial 60 plants was dead and left behind no juvenile shoots. Table 6 gives the record of juvenile shoot production in each bed. The average ratio of juveniles to parent (irrespective of whether the parent was still alive in September) was 1.4. This ratio of almost one and a half juveniles per adult, is considerably higher than the juvenile-to-parent ratio reported from any of the established stands where ratios ranged from 0.08 to 0.6.

Although the high ratio may, in fact, be related to the physical act of disturbing the cattail plants and therefore may be considered as a result of a physiological "defense" mechanism which triggers accelerated rhizome growth and juvenile shoot production, the fact remains that the cattail transplanting experiment was successful. This technique for increasing the distribution of cattails on mine slimes at Levack may be considered labour-intensive, but it is virtually 100% effective.

Eighteen cattail explants, secured in netting and placed in the dammed mine slimes on the pyrrhotite, will be checked next spring to determine whether they have survived the winter.

Table 6. Number of new juvenile shoots (<30 cm) in transplanted cattail stands in September.

Stand #	No. of mature plants	No. of juveniles	Ratio juveniles: mature
6	10	8	0.8
7	10	15	1.5
8	10	13	1.3
10	10	11	1.1
16	9	14	1.6
17	10	12	1.2
		average =	1.4

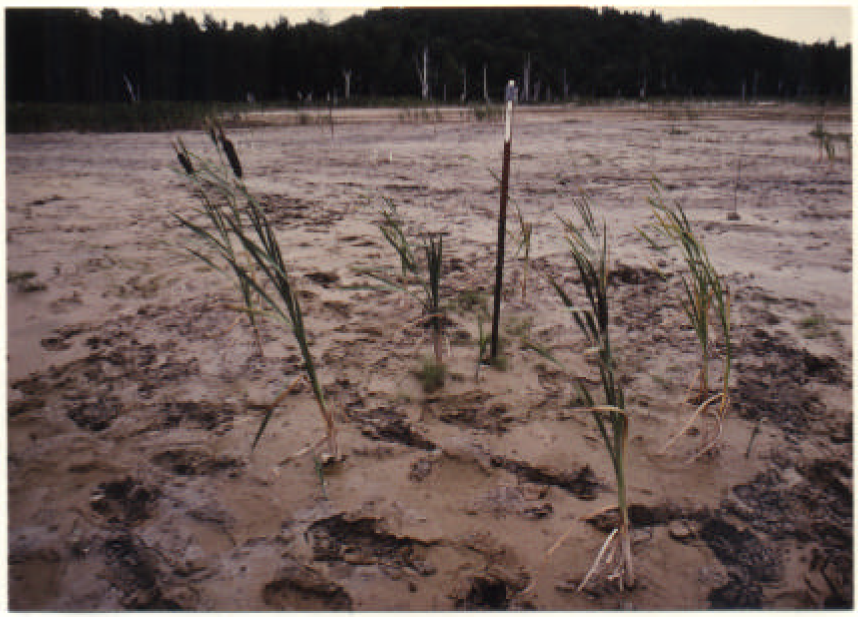


Plate 6. Transplanted cattail stand 7. Young emerging juveniles are evident.

Plant density of some cattail stands: The four stands (see Figure 1 for this location) which were marked off into areas during the initial field trip in July had the following range of cattail plant densities (as # plants/m^2): Stand A, 4.8 to 10; Stand B, 2.5 to 11.0; Stand C, 2.7; Stand D, 2.4. In 1986, we will evaluate the effect of cultivating the interior of the "established" cattail stands and compare the densities of four stands above with the cultivated plot.

3.1.2. Metal analysis of cattail leaves

Table 7 shows the metal content (ppm; $mg.kg^{-1}$) for cattail leaves and cattail leaf tips. There are 5 paired leaf samples, i.e. leaves collected from plants which were in the vegetative state (without the stalked "cattail" present) and leaves collected from the stalk bearing the brown cattail fruit. Two collections of vegetative leaves were made from the NW cove of the mine water retention pond. One was from a population of exceedingly tall (about 2 m) cattails in which there were few fruit-bearing individuals. The second was from an adjacent population of short plants (< 1.5 m) with numerous fruit-bearing individuals. There are also two collections of leaf tips from acid and alkaline cattails.

The reason for conducting the metal analyses on the cattails was founded on the observation that, in the acid creek the tips of cattail leaves (terminal 3-5 cm) were black. Frequently the outer border (1-2 mm) of either one of both edges of the leaves were also black. For cattails growing on the alkaline mine slimes, the tips were brown and occasionally there were brown edges to the leaves as well. Both colors---black and brown---indicated leaf cell death, but the "severity" of the toxcity problem appeared at least qualititively greater in the acid-grown cattail leaves.

Table 7. Concentrations of selected elements in cattail leaves.

CATTAIL CATEGORY/ LEAF TYPE	ELEMENT[1] CONTENT (mg.kg^{-1} dry wt) AL	B	CA	FE	MG	MN	P	S
Control								
vegetative	41.8	5.9	10339	80.5	3871	861	1666	1613
fruit stalk	54.4	6.4	13165	70.5	3958	1726	1618	1309
Falconbridge Conservation Area								
vegetative	92.5	6.8	9407	352	972	163	1828	3612
fruit stalk	91.0	8.6	11063	338	899	171	1532	4309
Falconbridge (high Ni)								
vegetative	34.6	6.3	3419	73	1471	279	1993	2168
fruit stalk	45.5	8.9	6976	113	1384	717	2591	3510
Levack Acid Creek								
vegetative	37.3	9.5	9350	632	905	941	1315	3938
fruit stalk	52.8	12.4	10669	575	986	1287	960	3065
leaf tips[2]	126.0	54.2	7681	3008	1155	2026	1230	5952
Levack Alkaline mine slimes								
vegetative	<19.0	5.5	12506	54.2	377	729	1253	1649
fruit stalk	25.6	10.1	14036	64.7	190	762	814	1150
leaf tips[2]	40.4	55.7	11928	172	646	2958	1570	2039
Levack NW Cove								
vegetative tall plants	<13.6	3.2	8944	63	566	385	1775	2703
vegetative short plants	<16.2	14.7	10663	70.2	505	113	1432	2266

1 - Elements whose concentrations were below detection by ICP: As, Cd, Co, Pb, Se, and Te

2 - Collected from both vegetative and fruit stalk leaves

Table 7 (continued)

CATTAIL CATEGORY/ LEAF TYPE	ELEMENT CONTENT ($mg.kg^{-1}$ dry wt) CU	NI	ZN
Control			
vegetative	7.8	2.6	11.1
fruit stalk	1.9	<4.8	13.0
Falconbridge Conservation Area			
vegetative	13.9	24.8	11.5
fruit stalk	14.0	32.7	10.7
Falconbridge (high Ni)			
vegetative	5.1	69.1	11.4
fruit stalk	3.9	74.5	9.9
Levack Acid Creek			
vegetative	16.8	40.3	8.4
fruit stalk	2.9	35.9	7.6
leaf tips*	9.6	91.0	15.9
Levack Alkaline Mine Slimes			
vegetative	3.6	10.8	8.7
fruit stalk	2.9	5.2	10.5
leaf tips*	9.1	<8.1	18.5
Levack NW Cove			
vegetative tall plants	7.3	13.3	12.2
vegetative short plants	5.8	10.1	11.7

* collected from both vegetative and fruit stalk leaves

The following points are of importance regarding the cattails growing at the 3 Levack sites:

(1) The quantitative mineral analyses (Table 8) support the hypothesis that substantial quantities of metals are absorbed by the cattails living in the acid creek. Especially significant are levels of Fe and S, when concentrations of these elements are compared with concentrations in the control leaves, i.e. acid creek is about 10 x the control value for Fe and 2.5 x the control value for S. The Fe content of the leaf tips of the acid creek cattails have 5x the level contained in the entire leaf (on a dry wt basis). It should be noted that on a dry wt basis, the tips concentrate many of the elements including Ni (91 ppm) and Mn (2,000 ppm), and the tips of the alkaline (mine slime) cattails do as well, but to a much lesser extent, e.g. for Fe, 2x the content of the entire leaf. Taylor and Crowder (1983a) mentioned similar leaf tip accumulation phenomena in their cattail studies.

From an ecological engineering standpoint, it would appear that cattails are potential scrubbers of Fe and S from the acid creek and consideration should be given to increasing the hydroponically grown cattail population in this waterway at Levack.

(2) As anticipated, the alkaline cattails growing on the mine slimes and those growing in the NW cove of the mine water retention pond had rather similar elemental concentration, e.g. Ni & Fe, but the former leaves had about twice the Ni content but little more than half the S content of the latter leaves. The high pH reduces the solubility of most of the metals, and they are, therfore, not "available" for absorption by the cattail roots.

(3) Generally there were no consistent differences in trends in a comparison of the element content of vegetative vs. fruit stalk leaves.

(4) As noted at the beginning of this section, one dense stand of cattails in the NW cove was exceedingly tall and healthy looking and the stand contained few fruit-bearing individuals. These cattails were as tall as those at the two Falconbridge sites and the one control site. Boyd & Hess (1970) concluded from their study of cattail "standing crop", i.e. the biomass of weight of plants per m^2, that of all the nutrients in the hydrosoils and water where the cattails were growing, only the P concentration was strongly correlated with biomass production. It is well known that mine tailings are very low in soluble P, particularly at alkaline pHs. What is particularly interesting, therefore is the fact that the P content of the cattail leaves from this tall stand in the NW cove is as high (or even higher than) as the P content from these former three locations.

Phosphorus is vital to the growth of plants---it is one of the three principal ingredients in most common fertilizers---and one may suggest that fertilizer applications to the Levack cattail stands, by foliar spray in order to avoid sediment and water pH problems, might increase plant productivity. The reason that an increase in plant biomass production is sought is that dry matter accumulation on the Levack mine slimes is currently very low. One of the basic tenets of ecological engineering is the creation and accumulation of an organic layer of plant debris on the surface of dry and submerged tailings in order to foster the establishment of additional plant species which can grow on the decayed litter but not directly on the mine slimes.

Table 8. Comparison of the concentrations of selected elements in the pre-bog creek, Levack, and leaves of its resident population of cattails.

Element	Conc. of element in Cattail pool of creek (ppm)[1]	Conc. of element in Cattail leaves (ppm)[2]	CF[3]
Al	20	23.3	™0
Cu	0.6	4.7	+7.8
Fe	1232	312.9	-3.9
Mg	114.5	490	-4.3
Mn	8.2	577.2	+70.4
Ni	26	19.7	-1.3
P	0.1	589.6	+5896
$SO_4^{=}$	5292	1814.5	-2.9
Zn	0.6	4.1	+6.8

1 - From Table 18

2 - Elemental data averaged for vegetative and fruit stalk leaves in Table 7; moisture content of 66% for cattail leaves was adapted from Kalin (1984) values for whole plants

3 - CF = concentration factor or relationship between elemental concentrations in the water and leaves; (+) leaves > water; (-) water > leaves

(5) The data in Table 8 compares the selected elemental content of the pre-bog creek water with the elemental content of the leaves of its resident population of cattails (in September, 1985). Because the uptake of elements by plants occurs via the roots, and the cattails are rooted in the sediments in the creek, we are not entirely justified in using elemental analysis of the creek water in the comparison with the elemental content of the cattail leaves. In fact such a comparison should be made using interstitial sediment water (=pore water) which is present in the sediments because these are the concentrations of elements to which the plants are actually exposed.

Table 9 shows similar data for a population of cattails growing in a "high Ni" bog (Falconbridge). As opposed to the pre-bog creek cattails, all elements in the "high Ni" leaves are above the concentration of the element in the bog water. It must be noted however that the same reservations discussed in the preceding paragraph apply to these data as well.

In addition, Bayley & O'Neil (1972) have reported that many elements show seasonal variations in their concentrations in cattails leaves. For example, Mg content has a midsummer peak. It should be noted that such seasonal dynamics of mineral nutrients are found in all perennial plants.

3.1.3. Carbon and nitrogen status of cattail leaves

Carbon content: The carbon content (C as % dry wt.) for the samples of cattail leaves from a number of sites is given in Table 10. It is immediately evident that the two Falconbridge collections and the two Levack collections (exclusive of leaf tip samples) have essentially similar carbon contents, i.e. 47-48%. The C content of the vegetative and fruit stalk leaves is also essentially similar; however, a slight difference is seen in the control plants. The control and NW cove plants had the lowest carbon content, i.e. 40.1%, for the vegetative "short" plants and 42% for the control vegetative leaves.

Nitrogen content: The organic N content (N as % of dry wt.) for the samples of cattail leaves is also given in Table 10. There is a rather wide range in values: from 0.95% for the fruit stalk leaves of the controls to 2.5% for the vegetative "short" plants from the NW cove. With one exception, i.e. the "high Ni" Falconbridge leaves, the %N was higher in the vegetative than fruit stalk leaves. When one groups the vegetative leaf N values according to the qualitative distinction of whether the plants are tall with long leaves or short with short leaves, i.e. the control, the two Falconbridge sites and the NW cove "tall" plants vs. the remaining 3 Levack sites, respectively, there is no similar separation of %N values. In both groups the values range between 1.5 and 2.0 (2.5)% N.

C:N ratio: The carbon to nitrogen ratio of plant organic matter is only a useful index if it can be empirically determined that there is a consistent relationship between the numerical value of the ratio and some biological or ecological factor. In the present case, we have grouped the cattail sites into those showing a vigorous plant growth (tall plants; long leaves) and stunted plant growth (short plants; short leaves). The C:N ratios are shown in Table 10 and it may be noted that, as with the %N (and %C), the two groupings of plants cannot be related to a similar grouping of C:N ratios. For the tall plant category, the C:N ratio ranged from 21 to 28; for the

Table 9. Comparison of the concentrations of selected elements in "High Ni" bog (Falconbridge) and leaves of its resident population of cattails.

Elements	Conc. of element in bog water (ppm)[1]	Conc. of element in cattail leaves (ppm)[2]	CF[3]
Al	12.0	25.0	+2.1
Cu	0.45	2.3	+5.8
Fe	3.3	48.1	+14.6
Mg	32.3	740	+23.0
Mn	2.1	258	+122.9
Ni	0.45	37.2	+82.7
P	Below detection limit	118.8	-
$SO_4^{=}$	539	1471	+2.7
Zn	3.3	5.5	+1.7

1 - From Table 17

2 - Elemental data averaged for vegetative and fruit stalk leaves in Table 7; a moisture content of 66% for cattail leaves was adapted from Kalin's (1984) values for whole plants

3 - CF = concentration factor or relationship between elemental concentrations in the water and leaves; (+) leaves > water; (-) water > leaves

short plants, from 16 to 32.

On the basis of the comparative N analyses, it does not appear that cattail growth on the alkaline mine slimes, in the acid creek or NW cove (short plants) are limited by N. It is interesting to note that the %N in the tall and short plant populations is essentially similar, with the latter only slightly higher than the former. There is a considerable difference in the C:N ratios because the C content in the short plants is 5% lower than in the tall plants. At this point, one must remember that carbon metabolism in plants is dependent on "high energy" phosphorus. We have seen in Table 7 that the P content of the NW cove short plants (1,432 ppm) is lower than that in the NW cove tall plants (1775 ppm).

Table 10. Carbon and organic nitrogen analyses of cattail leaves.

	Carbon and Nitrogen as % Dry Weight		
	% Carbon	% Nitrogen	C:N Ratio
Control			
Vegetative	42.0	1.5	28.0
Fruit stalk	46.8	1.0	46.8
Falconbridge Conservation Area			
Vegetative	48.1	1.7	28.3
Fruit stalk	48.0	1.5	32.0
Falconbridge (high Ni)			
Vegetative	48.3	2.0	24.2
Fruit stalk	49.0	2.2	22.3
Levack Acid Creek			
Vegetative	47.4	1.8	26.3
Fruit stalk	47.5	1.3	36.5
Leaf tips*	48.9	2.0	24.5
Levack Alkaline Mine Slimes			
Vegetative	48.3	1.5	32.3
Fruit stalk	47.0	1.0	47.0
Leaf tips*	47.2	2.5	18.9
Levack NW Cove			
Vegetative tall plants	45.2	2.1	21.5
Vegetative short plants	40.1	2.5	16.1

* collected from both vegetative and fruit stalk leaves

As noted above, the %C cannot be correlated with grouping plants according to their stature, but we should also emphasize that the P content of vegetative leaves can be related to the tall vs. short plant groupings (see Table 7). While the foregoing considers nutrient limitation, especially P as the hypothetical element which may be limiting growth of cattails, it is also possible that cattail growth is inhibited by an interaction of heavy metals and, in the case of the acid pre-bog creek, the low pH of the water as well.

3.1.4. General conclusions from cattail studies

The expansion of mature cattail stands growing on Levack alkaline mine slimes appears to be inhibited in those areas where there has been an accumulation and packing of layers of mine slimes and lime.

Experiments have been set up which will test this hypothesis and determine whether tilling mature cattail stands will improve their vigour and expansion rate.

Mature cattails growing on mine slimes were successfully transplanted to areas of the mine slimes which were devoid of cattails. Frequently the leafy portion died, but new shoots arose from the sub-terranean rhizome, i.e. the underground stem terminating in a new shoot.

Cattails growing on the alkaline mine slimes (pH 8-10) can be transplanted (hydroponically) to the acid creek (pH 2.5-3.5). While the aerial leafy portion of the cattails do not survive this drastic pH change, the rhizome and roots do survive. New shoots are produced and the plants become rooted into the creek bottom.

A hydroponic approach was also used to transplant cattails from mine slimes onto the inshore "slurry" of the mine water retention pond (2 locations) and the recently established pool of mine slimes which accumulated behind the artificial dam built on the pyrrhotite tailings.

In contrast with unfertilized control plots, fertilizer containing nitrate, potassium and phosphate accelerated the growth of young cattails on mine slimes.

The re-distribution of the discharged mine water and sand plant water has extended the mine slime delta out into the retention pond as a "tongue" which essentially divides the pond into one small basin (the N end) and a larger body of water. A "soupy" accumulation of mine slimes forming this new delta is now supporting a young, first-year population of cattails.

Metal analyses of cattail leaves showed that plants growing in the acid creek accumulated a considerable level of Fe and S. The "tall" population of cattails in the NW cove had a higher P content than all other populations at Levack.

None of the cattails growing on the Levack site seem to be deficient in N. However, phosphorus content of the cattail leaves suggests that the pre-bog acid creek and alkaline cattails are P-limited in comparison with the "tall" stand of cattails in the NW cove.

3.2. Waste Water Distribution Systems

3.2.1. The waste water system: Overview

The ongoing studies into the use of the ecological engineering in the revegetation of the Levack tailings area require the investigation and identification of suitable methods for the distribution of water to the surface of the tailings.

Since the Levack mill has been shut down, the water discharged to the tailings area comes from two sources. Water from the sand plant and minewater from the underground operation are discharged via two separate pipelines. Periodically, lime is added to the sand plant stream to control the pH. This causes periodic fluctuations of the input pH to the area as high as pH 11 to 12. Normally the pH of the sand plant water is approximately 5.1 at the pipe discharge and rises to approximately 5.4 as it crosses the tailings near the discharge (Table 11). The minewater pH is typically 4.8 and changes to 5.1 after traversing a short distance over the tailings surface. Most of the water which enters the tailings area is recycled for use in the sand plant (Figure 13). A relatively low volume of water leaves the area via the decant into Grassy Creek. Additional make-up water for the sand plant is taken from Moose Creek. Domestic wastewater is also discharged to the tailings area.

Table 11. Tailings area water pH.

LOCATION	SAND PLANT	MINEWATER
2 m from discharge	5.1	4.8
25 m from discharge	5.4	5.1

Five systems were evaluated in this portion of the project. The purpose was to identify those systems which would be most useful and efficient in distributing moisture for the growth of terrestrial moss on the surface of the tailings. These systems were to be run in parallel during the summer and fall period of 1985. Two of the systems involved periodic applications of water and three involved continuous flow from the existing tailings line. Flexible pipe and quick fit connections were used to facilitate the operation of the system in a more or less parallel mode.

The method of evaluating the overall performance of these systems was to be qualitative. Observations were made via anecdotal information collected by field staff. The following is a brief description of each of the systems considered.

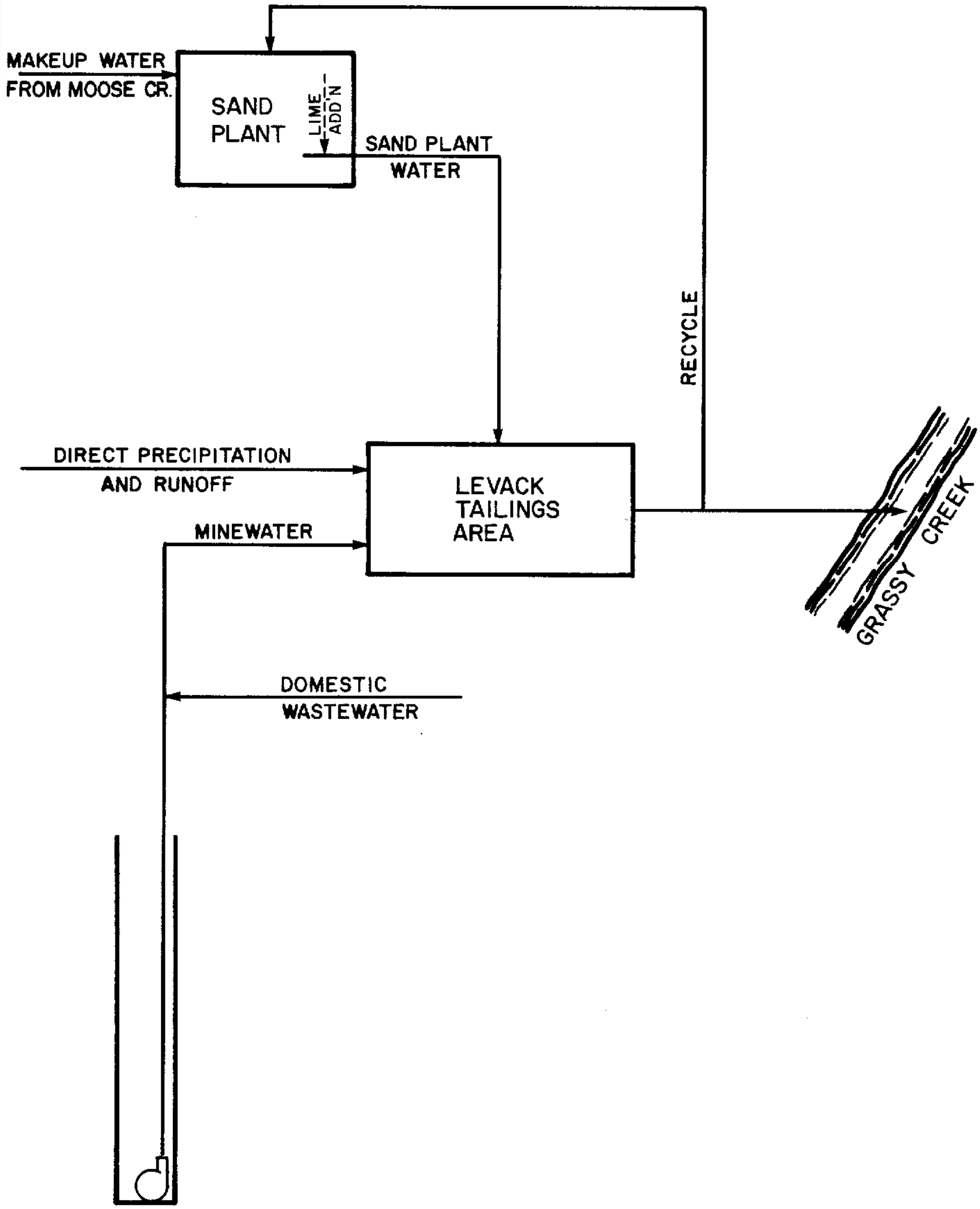


FIGURE 13
FLOW SHEET

3.2.2. System performance

The water distribution systems were installed by INCO personnel during the summer of 1984. The evaluation of the systems proceeded from that time until the end of operations for the project in September.

The data collected was in the form of anecdotes from INCO personnel on the relative ease of construction, and operation of the various systems. These data, although not quantitative, are considered useful because of the extensive field experience of the operational staff. Evaluations of the ease of construction were carried out with scale-up to a full scale utility and the ease of control of the construction parameters of the system. The availability of construction materials was also considered by the field staff.

The circular spray system was evaluated using only the head available from the tailings line flow. Periodic cleaning of the line was required to maintain adequate head for the operation of the impact spray head. The head available would be improved if a pump has been applied to the line. However, the field staff determined that this system was the easiest to install and control.

The linear spray system was also run at the ambient pressure of the tailings line. The flow was controlled by the use of a gate valve in the line at the exit from the tailings line. Regular cleaning was found to be required to alleviate head loss due to the sedimentation of solids in the line. Also it was found that the 1/4" holes recommended in the design were too small and were enlarged to 3/8". It was observed that the water streams from the linear system quickly formed channels in the surface and thus did not irrigate as large an area as hoped. This system was easy to construct in the field with readily available materials, and was flexible enough to be moved to other parts of the surface where water was required.

The split pipe was found to be less than satisfactory in terms of its ease of construction. It was modified slightly in the field to be a system using a perforated piece of derelict tailings line. This change eliminated the need for pipe cutting equipment onsite. However, construction difficulties included problems in the levelling of the pipe so that uniform flow from all holes could be achieved and the unwieldy nature of a long piece of pipe. In addition, the pipe was found to become clogged with fines from the tailings water during operation. This feature of the system would result in excessive maintenance requirements.

The flooded furrow system was intended to test an ancient method of irrigation which is well suited to granular soils with high capillary forces, in the plated structure of the pyrrhotite tailings. Construction of the furrows proved to be a difficult task when using the hand equipment suitable for the scale of the test plots. This could be overcome in full scale by the use of heavier equipment. Use of heavy equipment would of course be contingent upon the load bearing capacity of the surface. A major flaw in the test system appeared when the prototype furrows were filled with water. It was observed that the water quickly infiltrated into the tailings, with no migration by capillary action to the surface between the furrows. Accordingly, the system was deemed to have failed.

The use of small dams was investigated as a means of increasing the tortuosity of the tailings discharge streams as they travel across the tailings surface. This would decrease the average velocity in the channels, thereby reducing the tendency to erode large deep channels in the surface. Spreading the flow over a larger area would therefore result in shallow drainage courses and a greater area of wetted tailings. The dams were easily constructed by hand labour using polyethylene sheets filled with tailings. In the event of the failure of these structures, they could easily be rebuilt at minimal cost. Their performance was not appreciably impaired by settled fines upstream of the dams because their purpose was to redirect flow rather than create ponds of water on the surface.

From the discussion above, it can be seen that several of the systems tested had undesirable characteristics both from operational and construction viewpoints. The modified split pipe system can be eliminated from further consideration because of the difficulty of construction and the recurrent clogging problems. Flooded furrows were found to be unsuitable in the Levack tailings due to their inability to retain and transfer water to the tailings surface. In other tailings areas which are less free-draining, the furrow system may be suitable.

The linear spray system was easy to construct and flexible enough to be relocated on other parts of the site with ease. However, its performance in terms of distributing water evenly over the surface was impaired by the rapid coalescence of the small streams into larger channels. To permit efficient water distribution, this problem would have to be overcome by using a very extensive network of pipes on the surface. Since it was also observed that regular cleaning of the system was required, such an extensive network would require a considerable maintenance effort. Since one of the main requirements is low maintenance, this linear spray system has potential drawbacks.

The two remaining systems tested, namely, the circular spray and the stream distribution systems, were found to have suitable characteristics which suggested that they might be used in further studies. The circular spray is a variation of a system widely used in agricultural irrigation. It is a simple system which irrigates a large area with a minimum of equipment. The equipment used is simple, easily maintained and portable. It is also important to note that the existing familiarity of the staff with the system will aid in proper operation. However, for moss irrigation, the circular spray system may not be suitable, since the impact of the spray was considerable as indicated by the depressions cut into the pyrrhotite. To promote moss cover development, this physical stress is likely to be counterproductive. Both the linear and circular spray systems will be tested for moss irrigation in the 1986 program.

The stream distribution system had the characteristic of being easy and inexpensive to construct and highly efficient in distributing the water flow. Accordingly, it is also recommended for further development in the 1986 program as a method for utilizing waste water in final years of operation of acid generating tailings surfaces.

3.3. Moss Cover Establishment and Promotion

3.3.1. Acid generation and vegetation covers: Means of measuring oxygen penetration

The objective of this section of the contract was to review methodologies which have been developed to determine oxygen in soils and to evaluate which, if any, of these methods may be useful in a study of the degree of reduction of oxygen penetration through various kinds of vegetation covers on acid-generating mine tailings. Kalin (unpublished data) has photographically recorded qualitative observations that the depth of the oxidized pyritic tailings varies with the kinds of plants growing in the tailings surface. More quantitative chemical data are needed to support these field observations of variable oxygen diffusion in tailings as a function of vegetation cover.

In the literature survey we evaluated the reports according to three important criteria which are relevant to the problem which we have defined: (1) the scale of study where instrumentation was developed and employed; (2) the laboratory versus field applications; and (3) the application of the technique to unique conditions present in pyritic and pyrrhotitic tailings.

(1) Scale of study

Many of the mining related studies may be represented by a most recent and excellent article on oxidation of pyrite in a waste rock dumps (Harries and Ritchie, 1985). The authors studied O_2 and CO_2 dynamics in waste rock dump approx. 15 m high by 500 m diameter at the base. They were able to employ both O_2 and CO_2 analysers for gas analysis taken at depths throughout the waste rock heap. Although their techniques are not suitable to our requirements due to two problems of "scale", i.e. (i) we are interested in only the upper 10-15 cm of tailings cover, and (ii) tailings porosity will usually be quite low (with the exception of fissures in hard pan or stratification of layers), the authors duly recognize two factors which would retard entry of oxygen into the waste rock heap, namely: water, a poor oxygen transport vehicle due to low oxygen solubility (relative to air) and porosity reduction, particularly on the top and sides of the dump.

It is well to point out that these are two of the basic tenets which Ecological Engineering methods try to bring about on tailings sites: redistribution and retention of water over as much of the acid-generating site as possible. Specific to the Levack situation, is the covering of the surface of coarse, acid-generating tailings with either alkaline or acidic mine slimes to reduce porosity. It may also be parenthetically and ironically noted that the goals of acid generation reduction, sought by Harries and Ritchie (1985) and ourselves, are diametric to budding technology in the mining industry of heap-leach design (cf. Cathles and Schlitt, 1980).

The classic lysimeter, with its design problems, is continuously being modified (see Morrison, 1982) but again, the size of these soil pore water collectors excludes their practical use in the study of shallow depth oxygen penetration which we will be undertaking.

(2) Laboratory versus field

The perennial problems of "bringing the field into the laboratory" become particularly clear when one is dealing with high Fe, SO_4 and extremely acidic pyrrhotitic tailings. The use of "lysimeters" - in this sense, the term applies to containers holding soil, sediments, etc., which are outfitted with sampling ports - is wholly inadequate for our purposes. Although improvements in design of these instruments have also been made for use in studying aeration of water-logged agricultural soils (Blackwell, 1983), on the scale at which we will be working, the container-tailings interface will produce "container-effect" (especially well-known in greenhouse plant physiology studies) which will obscure the chemical observations which we are trying to monitor.

Plate 7 shows a 4-ft deep below-ground tailings monitoring station which was dug into the tailings by INCO staff. The device was intended to be used in the evaluation of the effective penetration depth of lime application. Access holes in the wooden sides of the "casson" were cut at 6" intervals. The pH of exposed tailings was measured periodically and the results are shown in Table 12. The initial pH's (July 4) ranged from 3.1 to 3.5 for all depths (except 1, with a pH of 4.8), while the surface pH was 3.6. After liming, the first measurements of surface samples (August 3 and 16) showed the pH to have increased to 6.1 and 6.3. Later measurements showed no significant amelioration of pH attributable to liming at a depth greater than 6", i.e. below the first sampling port, and that improvement at this depth (to pH 4.1) was only recorded on August 16. For the remaining sampling dates, the pH's below the surface were below 3.7.

It is not unreasonable to conclude that exposure of the tailings surface to atmospheric oxygen behind each of the windows probably contributed to the obscuring of any positive effects of the liming, particularly in the first 6 to 12 inches. Again, one must re-iterate the problems involved when an artificial surface is exposured to air. The newly created surface which readily reacts with oxygen is the same one which is intended to be used for monitoring the effects resulting from a treatment applied to the "real surface" (90 degrees with respect to the "observation" surface). Nevertheless, the field is the only satisfactory place where instantaneous measurements, encumbered by a minimum of technical and intrumental problems, may be made to satisfactorily evaluate oxygen penetration in acid-generating tailings on the scale at which we are focusing our attention.

(3) An appropriate chemical method with potential application for acid tailings studies

As noted above, photographic records (Kalin, unpublished data) show that tailings underlying a moss cover remain more compacted, and oxidized to a lesser depth (oxidized = orange; reduced = grey) than tailings underlying a cover of rooted plants (grasses and small shrubs). While rooted plants obtain oxygen for root growth from both the soil and through the plant, depending on the soil availability of oxygen (Luxmore and Stolzy, 1982), the roots probably export very little oxygen into the soil if the soil itself has a low oxygen tension. Roots, on the other hand, do respire and release CO_2 into the soil as well as soluble, low molecular weight organic matter. Sugars, amino acids and variety of more complex substances may be used as carbon sources by microflora, which include the acid-generating bacteria.

Plate 7. Plywood "casson" installed on INCO tailings to study the effect of liming on pH profiles in the tailings.

Table 12. pH measurements through soil profile in Sunken box on Copper Cliff tailings.

SAMPLING PORT (at 6-inch intervals)	SAMPLING DATES (1984-1985)									
	1984							1985		
	July 4	August 3	16	29	Sept 17	October 1	17	May 17	June 14	July 19
Surface	3.6	6.1	6.3	---	---	---	---	---	---	---
1	4.8	3.6	4.1	3.6	3.1	3.6	3.3	3.8	3.6	3.6
2	3.1	3.4	3.7	3.5	3.2	3.7	3.3	3.4	3.3	3.2
3	3.5	3.4	3.8	3.6	3.2	3.4	3.3	3.4	3.3	3.4
4	3.2	3.2	3.7	3.4	2.8	3.5	3.2	3.2	3.3	3.3
5	3.5	3.5	3.7	3.5	2.8	3.6	3.4	3.3	3.4	3.4
6	3.4	3.5	3.5	3.5	3.2	3.6	3.3	3.5	3.6	3.5
Water	---	---	---	---	---	---	---	5.8	6.1	---

Meanwhile, roots of woody plants are structures which may be as physically dynamic as the above ground portions of plants. Responses of roots to daily water stress cycles may include changes in root diameter. As an example, the girth (circumference) of above ground stems is less during mid-day than late evening or early morning. While a full discussion of water relations in plants is beyond the scope of the present report, what is important to recognize is the physically dynamic nature of roots which create movement of substrates by virtue of their own growth and expansion and contraction.

What does root movement do to tailings? As noted above, oxygen penetration into the waste rock heaps is related to porosity (cf. Harris and Ritchie, 1985). Roots increase this tailings porosity by breaking up the superficial layers of fine tailings. The chemical evidence, supplementing the photographic records, for increased oxygen penetration into tailing carried with rooted vegetation vs. those covered with a layer of moss which produces no roots, may be potentially obtained using a simple and elegant qualitative test for reduced (ferrous) iron - Fe^{+2}. In this method, a solution of , -dipyridyl in 1 M ammonium acetate may be sprayed on an excavated surface or small samples of tailings may be placed in a vial containing the reagent and shaken. The positive test for the presence of Fe^{+2} is immediate formation of a ferrous- , dipyridyl complex, which is a red precipitate (Batey and Childs, 1982).

One of the desirable features of the techniques which were reported by these authors for agricultural soils, was that a microstructure of oxidized and anaerobic areas within the same soil horizon could be detected with the spray application of the reagent. Compacted zones were anaerobic, giving the red, ferrous precipitate, while cracks and loose clumps might give no reaction.

Conclusions and recommendations

The uni-directional penetration of atmospheric oxygen into tailings may be reduced by keeping the tailings water saturated, covering tailings with finely porous material and finally by covering the latter material with a kind of vegetation, namely, mosses, which does not create fissures in the tailings which would allow the penetration of oxygen. Roots of vascular plants increase the porosity of tailings and thereby increase oxygen penetration.

The foregoing is viewed as a strong hypothesis in need of chemical data to support photographic evidence. We have reviewed the literature of relevant techniques for direct oxygen measurement and none of them is without drawbacks: (1) due to the scale at which one must conduct the experiments and (2) the requirement to conduct the experiments in the field. An indirect, qualitative assessment of the oxygen status of tailings is the presence of Fe^{+2}, indicating the existence of anaerobic conditions. A colorimetric (precipitate-forming) method has been published (Batey and Childs, 1982) which may be useful in detecting the presence of anaerobic conditions in superficial (<10 cm thick) layers of tailings.

3.3.2. Identification of both indigenous mosses at Levack and those introduced onto the Levack site

An important objective of the RATS study is to develop methods to establish a moss cover on the pyrrhotite tailings which will not only be applicable to the particular field situation at Levack but also to pyritic tailing sites. A list of indigenous moss species currently growing at Levack is given in Table 13. A list of species collected at other mine sites for introduction into specific areas at Levack, e.g. pre-bog acid creek and pyrrhotite tailings are presented in Table 14.

Table 13. Indigenous mosses collected on Levack tailings and other INCO sites.

SPECIES	LEVACK SITE
Pohlia nutans	Cattail area by island
Pohlia sp. Bryum argentum	Both appeared on mine slimes in response to application of Scott's fertilizer
	INCO SITE
Ceratodon purpureus	Rubber dump at Copper Cliff
Funaria hygrometrica	Rubber dump at Copper Cliff
Bryum bicolor	Rubber dump at Copper Cliff

Table 14. Species of mosses introduced onto the Levack site.

SPECIES	COLLECTION SITE	HABITAT CHARACTERISTICS	INTRODUCTION SITE ON LEVACK
Polytrichum commune	Nickel Rim	Semi-aquatic acidophilic	Acid creek
Drepanocladus fluitans	Olive Lake Elliot Lake	Aquatic; acidophilic	Acid creek
Leptobryum pyriforme	Falconbridge	Terrestrial; acidophilic	Fine pyrrhotite tailings

The most common moss on the mine slime was Funaria hygrometrica and this species was used in transplant experiments as an alkaline "tolerant" moss (Plate 8).

The acidophilic moss collected from a Falconbridge site remained in a thread-like gametophyte stage until mid-September. It developed a more robust character in the early fall and only at this time could it be positively identified as Leptobryum pyriforme.

Acidophilic mosses: The location of the acidophilic moss (L. pyriforme) transplants are shown in Figure 10. The moss growing on acid mine slimes was most amenable to the slurry technique because the fine substrate was easily broken up and mixed into the coarser pyrrhotite. Of the two amendments, sand and sandy topsoil, the former mixed into the pyrrhotite and then slurried with the moss gave the clearest indication that the moss could survive and spread on the pyrrhotite. Some of the pyrrhotite plots with the Leptobryum pyriforme were flooded by alkaline water from the sand plant discharge pipe and were killed. Likewise, the moss did not survive in the mine slime plots due to their alkaline nature.

At the time of the last field trip in November, there was some evidence that L. pyriforme had spread onto the pyrrhotite from large clumps of the acid mine slimes set into the pyrrhotite-sand surface. In November, a greenish haze could still be seen where the moss had spread over the slurried pyrrhotite.

Alkaline-preferring mosses: The location of the alkaline-preferring moss transplants is shown in Figure 10. The alkaline moss (Funaria hygrometrica) was not easily broken up. This moss was robust, "fruiting" (producing spores) and densely compacted, presumably held together by interwoven rhizoids (root-like threads) in the upper few centimetres of the mine slimes (Plate 8). Where the experimental transplant plots did not get washed over by the unexpected flushing from alkaline sand plant water, there was a general indication that the moss was spreading on the mine slimes, regardless of the kind of amendment: sand, sandy topsoil or no addition (control). In September, a light greenish haze in the form of "halos" around individual clumps of the transplanted moss suggested that the alkaline moss was spreading.

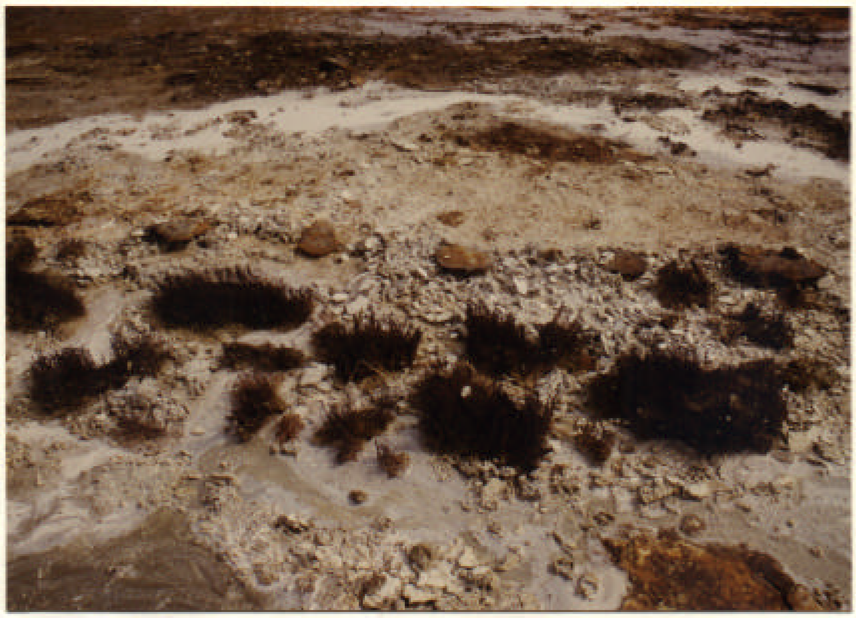


Plate 8. Alkaline moss (Funaria hygrometrica) transplant studies on the Levack mine slimes. Transplanted clumps in the bottom half of the photograph; slurried moss plants incorporated into slimes above spaced, stoned slabs.

It should also be noted that the L-shaped water distribution system which irrigated the moss transplant plots was also distributing a thin layer of mine slimes over the pyrrhotite. One problem with the moss experiments was that initially two types of water were expected - acid and alkaline. However, as indicated in Table 15, the pH ranges of water irrigating the experimental moss transplant plots on the pyrrhotite ranged from 4.3 to 12.4, not suitable for systematic experiments.

Much of the newly deposited mine slimes were also covered with a fine green haze. We presently attribute this expanding moss population to the "seeding" from the established alkaline moss population growing on the "banks" of the mine-water creek flowing down the tailings to the east of the L-shaped irrigation piping. Whether these spores were blown or carried by water to the new surface of mine slimes or carried there on the soles of boots cannot be determined. (Note: the latter is a most reasonable and serious alternative as our experience with accidental planting of vascular plants (e.g. field sorrel) seed in foot prints on mine slimes attests).

Table 15. pH of water in the perforated pipe distribution system irrigating the experimental moss transplant studies.

	Perforation number in right (R) or left (L) arm of water distribution system*					
Date	June (L)	June (R)	Aug 8 (L)	Aug 8 (R)	Sep 12 (L)	Sep 12 (R)
1			9.2	11.4	8.1 to 8.3 over	
2	9.1				length of both pipes	
3		7.2	12.4	11.1		
4			9.9			
5	6.6		11.0	9.3		
6		5.6	11.0			
7			9.5			
8				8.8		
9	5.5	4.5				
10			9.1	8.9		
11						
12	5.2	5.2	9.3			
13						
14				8.6		
15	4.3	3.8	9.0			

* pH measured in small pools of water on the pyrrhotite formed by the confluence of small streams of water from the perforations in the pipe.

3.3.3. Fertilization of mine slimes promotion of indigenous moss cover

The rudiments of a moss cover were already evident at the beginning of the summer program in June 1985 (Plate 9).

As noted earlier the serendipitous result of the cattail fertilization experiments was the finding that the areas of young cattails which received fertilizer (e.g. household garden variety) displayed a remarkable growth of mosses and bluegreen and green (unicellular algae) within 3 weeks (Plate 10). These mosses were identified as Bryum argentum and Pohlia sp. The plots were checked in November but the entire area was flooded and frozen and the surface of the mine slimes could not be seen.

A second set of fertilizer experiments was conducted with the three kinds of fertilizers currently used by INCO agriculture. The results of the latter experiments were rather striking (see Figure 10 for layout and location of the experimental plots). Foremost was the observation that the indigenous species of moss growing on mine slimes do not respond favourably to superficial cultivation and raking in of straw, sand or sandy-topsoil (Plate 11). These techniques seemed quite disruptive. The second significant result was that the plots fertilized with the two fertilizers containing NH_4 - either in the form of NH_4NO_3 or urea - killed the moss which was there in the plot. One should also note that these two fertilizers contained no phosphorus (P) or potassium (K).

The plot fertilized with Nutrite, which contained NO_3 PO_4 and K, showed an increase in moss cover when compared with the unfertilized control plot. The Nutrite fertilizer was not too different from the two Scott fertilizers, but the Nutrite results were less dramatic - possibly because the experiment was started later in the summer when already the temperature was decreasing and the active growth phase of mosses was presumably past. In November, the Nutrite fertilized plot was still green while no mosses were evident on the remainder of the mine slime area, including the unfertilized control.

On the basis of these fertilizer results, a light spread of Nutrite was broadcast over the entire moss transplant area - pyrrhotite and mine slimes (the latter surface was first punctured with rake teeth to retain the fertilizer pellets). While not beneficial to the mosses this year, fertilizer could be taken up by the mosses and stored over winter, giving the moss a growth boost in spring 1986. A plot of established alkaline moss near the waste rock dump was also fertilized.

While a straw amendment, dug into the pyrrhotite and mine slimes, did not promote moss expansion, a light superficial straw covering spread on the mine slimes in June was definitely beneficial. Moss flourished under the loose straw in July and August (Plate 12). There are a number of reasons for this promotional effect: (1) the straw kept the sediment surface moist yet permitting air exchange (the mosses need a CO_2 supply to photosynthesis); (2) some nutrients may have been leached from the straw and/or (3) the straw may have been providing some shade.

In summary, we may state that our field experiments have yielded positive and useful results, both for acidophilic and alkaline mosses. It now appears that a sand amendment is needed before Leptobryum pyriforme can get

Plate 9. Naturally-occurring moss cover growing on alkaline mine slimes between island and shoreline of mine water retention pond.

Plate 10. Fertilization of young cattails. Area receiving fertilizer was between the stakes. Note the grey-blue cover of mosses and bluegreen algae in addition to the young grass-like cattail seedlings. Control area receiving no fertilizer extended from the farthest stake to the cattail stand in the background.

Plate 11. Experiment to test the effect of various amendments on the growth of indigenous moss cover on Levack mine slimes.

Plate 12. Mine slimes receiving fertilizer and straw amendment. Note boundary between fertilized area on the right and unfertilized area on the left.

established on pyrrhotite. This is probably a "physical" requirement when one considers the nature of the original habitat of L. pyriforme on acid mine slimes and the coarse, shale-like character of the unamended pyrrhotite. The sand may give the Leptobryum rhizoids (root-like threads) a foothold on the sand-pyrrhotite mixture.

In comparison with the pyrrhotite situation, the indigenous alkaline moss does not do well when the surface of the mine slimes are disturbed. In one sense, disturbing the surface of the mine slimes is creating a situation analogous to unamended pyrrhotite, i.e. a broken up surface where moss rhizoids cannot become anchored. By contrast, the addition of sand to pyrrhotite creates a physical consistency or the tailings which is analogous to undisturbed mine slimes. Perhaps the physical---as opposed to chemical, i.e. acid versus alkaline---requirements of these mosses are not too dissimilar.

3.3.4. Greenhouse experiments

The mosses used in the greenhouse drainage experiments from both collection sites (the Rubber Dump on the Copper Cliff tailings and the Levack mine slimes) were identified as Funaria hygrometrica.

The results of the drainage experiment (Plate 13) showed that the method of drainage per se did not noticeably affect growth of this moss. However, maintenance of sufficient moisture had a significant effect on the amount of growth observed. In the early part of the experiment (in the main greenhouse) when the normal-drainage treatments were allowed to dry out completely due to high temperature and light conditions, the moss did not spread or form new layers. The other two treatments where the moss was kept moist showed better growth and a healthier (greener) appearance.

During the 12-week monitoring period, the moss trays were placed in the cold-frame where temperature and light conditions were more moderate; the normal-drainage treatment did not dry out in this situation. During the remainder of this experiment, the mosses were kept moist in all treatments. Little difference in overall growth response was observed. In fact, the main differences between various treatments can, more appropriately, be attributed to differences in the condition of the original samples. The best growth response was observed in Tray # 8 where up to 9 layers of moss could be distinguished at the end of the experiment.

This sample, however, was the healthiest (based on colour) sample with the most complete moss cover at the time of collection; this sample was growing directly on the lime added to the tailings. The other samples (Trays # 9 to 14) initially were less healthy in appearance, were growing directly on tailings (with little lime present) and/or had less moss cover. During the experiment, the moss tended to spread over the substrate surface until it was covered, before developing additional layers. Therefore, growth (as addition of layers) was not as high in these samples (with an average of 3 to 4 distinct layers) as in (Tray # 8).

The normally-draining sample from Tray # 8 also grew appreciably better than the other normally-draining samples. Since the Tray # 8 sample had a complete moss cover at the beginning of the experiment, it is possible that

Plate 13. Moss experiment in INCO greenhouse: water drainage experiment.

Plate 14. Moss experiment in INCO greenhouse: techniques for transplanting Leptobryum pyriforme onto Levack pyrrhotite with various substrate amendments. Note "slurry" technique in centre foreground box with greenish coloration spreading over sand-pyrrhotite substrate.

water was retained longer than in the other samples thus preventing the desiccation which occurred in the early weeks of the experiment.

The moss cuttings taken throughout the experiment will have been examined relating growth increments to the observations which can be obtained by visual examination, i.e. layers of growth. If the addition of layers as reported during the experiment can be directly correlated with growth increments on the moss plants, it should be relatively easy to apply this method in growth experiments in the field.

C. Manville examined in detail several series of moss cuttings. The microscopic investigation of dried specimens showed rather disappointing correlation of the counting layers, observed immediately after cutting. This observation did not change, when, in an attempt to approximate the conditions of the harvest, the plants were sprayed with water.

Because of the discrepancy between observations (layers), a quantitative measure of length was used to estimate the total growth of the moss caulids (i.e. "stems") from the surface of the substrate to apical growth. All measurements were in millimeters. Table 16 is a summary of the growth rates in all experiment. The percentage change in length is given in the right hand column.

Manville's observations substantiated those of Brumelis (1982) that there are seasonal and possibly annual growth increments in <u>Funaria hygrometrica</u>. Note than many ot the samples taken also contained <u>Leptobryum pyriforme</u> as a contaminant. The recommendation from these observations is that total length has to be used as a quantitative measure of growth rather than the number of layers which are subjective estimates and are not a reliable measure.

The amendment experiments carried out in the greenhouse parallelled those amendments made in the field experiments with the acidophilic moss <u>L. pyriforme</u> and the alkaline moss <u>F. hygrometrica</u>. The experiments indeed gave similar results. In the case of the <u>L. pyriforme</u> moss, sand mixed with pyrrhotite and slurried with the moss gradually produced a green haze over the slurried portion of the dynamite box (Plate 14) when compared to the portion containing the initial clumps of moss on the original acidic mine slimes.

The results of the alkaline moss on the mine slimes were not as convincing as those seen in the field trials on the Levack tailings, i.e. the greenish halos indicated of spreading moss filaments were not as conspicuous.

Table 16. Observations of the growth in number of layers and in total caulid ("stem") length in the moss Funaria hygrometrica. Initial number of layers recorded on wet moss samples at beginning of experiment. Final number of layers recorded on dried moss samples after completion of growth experiments. Caulid lengths recorded on dried samples at end of experiment.

EXPERIMENTAL SERIES	TIME PERIOD	NO. OF MOSS LAYERS OBSERVED Aug.	Sept.	Oct.	% GROWTH
8-1	initial (wet)	3	6	8-9	
	final (dry)	2	2	2	
	caulid length (mm)	7.0	7.0-7.5	8.5-9.0	28.6
8-2 A	initial (wet)	3	3-4	4-5	
	final (dry)	2	2	3	
	caulid length (mm)	3.0	3.5	7.0	133.3
8-2 B	initial (wet)	2	3-4	4-5	
	final (dry)	2	2	3-4	
	caulid length (mm)	4.0	4.0	10.0	150.0
8-2 C	initial (wet)	2	3-4	3-4	
	final (dry)	2	2	2	
	caulid length (mm)	2.5-3.0	2.5-3.0	2.5-3.0	0.0
8-2 D	initial (wet)	2	2-3	3-4	
	final (dry)	2	2	3	
	caulid length (mm)	5.0	5.5	5.5-6.0	10 - 20
8-3 A	initial (wet)	2	3-4	4	
	final (dry)	2	3-4	3-4	
	caulid length (mm)	5.5	7.5-8.0	11.5	109.0
8-3 B	initial (wet)	2	3-4	4	
	final (dry)	3	3-4	3-4	
	caulid length (mm)	6.0	8.0	10-11	83.0
8-3 C	initial (wet)	2	3-4	4	
	final (dry)	2	2	3	
	caulid length (mm)	5.0	5.5	6.0-6.5	20 - 30

3.4. Wetland species selection for extreme conditions

3.4.1. Extreme alkaline conditions

Transplants from Conservation area: The transplanting experiments for *Phragmites*, *Juncus*, *Carex* and *Potamogeton* indicated that out of these 4 species introduced, 3 (*Phragmites*, *Juncus* and *Carex*) produced new shoots; only *Potamogeton* did not survive transplantation into the mine water retention pond.

Chara introductions: The *Chara* had been introduced into the pond in early May. Towards the latter part of May there was an unanticipated dumping of approximately 600 gallons of alkali into the mine water retention pond of the NW cove. We feel that this had a detrimental effect on the *Chara* growing in the pond. A certain amount of growth had taken place (ea. 10-15 cm) but then the plants became white and were obviously dead. A second introduction of *Chara* was made in July at the same locations along dam 1. Plants emerged from the netted racks again to a similar length, however all were dead by September.

Plants were also introduced into the Conservation Area (at Falconbridge) in similarly alkaline flocculant sediments, but in water of greater depth; these transplants showed extensive growth. The failure of the plants to establish at the Levack site cannot be explained since no time could be allocated to monitor the water conditions during the project. Several factors may have contributed to the failure of *Chara* in the mine water retention pond, e.g., physical exposure along the shores of dam 1 and some extreme pH fluctuations during mine shut down in the pond.

Given that both introductions (May and July) showed considerable growth prior to death, more attention should be devoted to monitoring the conditions in the mine water retention pond during establishment of *Chara*. Useful information can be obtained in determining the causes of death for the overall development of the *Chara* Process.

Indigenous species record: The main species which were identified were horstails (*Equisetum arvense*), Sorrel (*Rumex acetosella*), willows and various grasses. The results of percentage cover estimates within each quadrat for the period from July to September, 1985 and the records of the mulching experiments are given in the Appendix. These data, for which no "trends" are yet obvious, are the "baseline" data set against which transect plant cover will be compared in subsequent years of the RATS study on the Levack tailings.

Water chemistry of mine water retention pond: Table 17 gives the water chemistry data for the mine water retention pond sampled near the new waste rock dam, the gravel pit on the opposite side of the waste rock dam as well as chemical information on the waters pumped onto the Levack site from the mine and from the sand plant.

Table 17. Chemical analysis of waters on Levack site including mine and sand plant discharges and the retention pond.

PARAMETER	Discharge Waters: Mine Water	Discharge Waters: Sandplant	Mine Water Retention Pond	High Nickel Cattail Bog (Falconbridge)
Date - 1985	26/06	26/06	12/09	12/09
pH			9.1	3.05
Cond (uS/cm)				
Alkal (tot)			16	< 2
Hardness			910	310
Tot Solids			1842	760
T.S.S.			11	1
Redox (mv)			-110	
Elements (mg/L)				
Ag	b.d.	b.d.	b.d.	b.d.
Al	23.6	12.8	1.09	11.99
As	0.023	0.045	b.d.	b.d.
B	0.07	0.24	0.067	0.037
Ba	0.51	0.148	0.107	0.021
Be	0.001	0.001	b.d.	0.008
Bi	b.d.	b.d.	0.02	b.d.
Ca	347	285	393.1	71.04
Cd	> 0.002	> 0.002	b.d.	b.d.
Cl			115	10
Co	0.022	0.32	0.019	0.259
Cr	0.0509	0.039	0.01	0.006
Cu	0.142	1.02	0.015	0.447
K			59	5.2
Mg	14.6	69.5	30.34	32.25
Mn	0.551	0.847	0.071	2.13
Na	131	129	145.3	6.27
Ni	0.387	23.9	0.015	0.447
P	0.529	0.461	b.d.	b.d.
Pb	0.085	0.083	b.d.	b.d.
Pt	< 0.073	< 0.073	b.d.	b.d.
Rh	b.d.	b.d.	b.d.	b.d.
Sb	b.d.	b.d.	b.d.	b.d.
Se	0.152	b.d.	b.d.	0.107
Sn	0.013	0.013	b.d.	b.d.
Te	b.d.	b.d.	b.d.	b.d.
Ti	1.19	0.296	0.023	0.004
V	0.04	0.014	0.006	b.d.
Zn	0.189	0.47	0.029	0.264
NO3-N			41.1	< 0.1
NO2-N				
NH3-N			1.6	0.1
CO3			< 2	< 2
SO4 (dis)			1348	539
Fe (tot)	22.1	27.5	0.829	3.33
Fe (2+)			0.647	3.33
Fe (3+) (calc)			0.182	

b.d. below detection limits

3.4.2. Extreme acidic conditions: pre-bog-acid creek

Transplanting of acidophilic Ulothrix: Acidophilic Ulothrix raised in the laboratory of Boojum Research, was transplanted to several sites in the pre-bog acid creek. The Ulothrix was first implanted in 15 cm long sections of "Loofa" sponges, i.e. the elongated cellulosic network of a tropical, 3-carpel fruit, which is commonly sold as a back-scrubbing sponge. The rationale for using this method of "seeding" Ulothrix was that, while trapped in the inner network of cellulose strands, the bulk of the Ulothrix would remain in the Loofa while growing strands of the alga would freely elongate through the porous cellulose network and presumably break off to be carried downstream to colonize new locations in the creek.

Based on our previous experience, the pH of the creek (see Table 18) was not too low for the Ulothrix. However, the alga did not survive. The reason for this is not clear but may be related to the exceedingly high iron and sulphur content in the water (Table 18).

An aquatic moss and a semi-aquatic moss (see Table 14) transported from Nickel Rim and Elliot Lake, respectively, were planted in the acid creek in July however establishment or indications of adaptation to these conditions were not noted by the end of the season. Conclusive observations are anticipated by spring 1986.

3.4.3. Water chemistry of the acid creek

Water chemistry data for the Euglena or "pre-bog" acid creek are given in Table 18 for June 26 and September 12, 1985. There are both quantitative and qualitative differences between the two months when one compares water chemistry for two of the sites on the creek: 1) the trestle pool at the head of the creek, and 2) the pool at the foot of the creek containing the acid cattail stands (see Plates 15 and 16).

pH: The pH of the pre-bog acid creek was essentially unchanged at pH 2.5 to 2.7 throughout the summer season.

Nitrogen: NO_3^- concentrations were similar (3.5 ppm) at the trestle site during both months. The concentration was ten times lower in the cattail pool in September than in August, i.e. < 0.1 vs 1.04, respectively. There was a decreasing gradient in NO_3^- concentration from the trestle to the cattail pool, and in contrast, the NH_4^+ concentration gradient was in the oppposite direction (from 0.9 ppm at the trestle to 1.9 ppm in the cattail pool).

Sulfate: SO_4^{-2} concentrations are rather similar at the trestle site in June and September, but the SO_4^{2-} concentration in the cattail pool is lower than that in the trestle pool during June and higher than that in the trestle pool in September. At present, there is no ready explanation for these differences.

Iron: The concentration of total iron is slightly higher in September than in June. There's a substantial decreasing gradient from the trestle site to the cattail pool in June (> 300 %) but the concentration difference between sites may not be significant in September. The ratio of Fe^{2+}:Fe^{3+} increases from

Table 18. Pre-bog acid creek: physical and chemical data.

PARAMETER	Trestle Pool	PRE-BOG Cattail Pool	ACID Trestle Pool	CREEK Middle Pool	Cattail Pool
Date - 1985	26/06	26/06	12/09	12/09	12/09
pH					
Cond (umhos/cm)					
Alkal (tot)			< 2	< 2	< 2
Hardness			2000	2100	1700
Tot Solids	6250	2118	8584	8766	7832
T.S.S.	1008	40	11	4	5
Redox (mv)					
Elements (mg/L)					
Ag	0.013	< 0.005	< 0.046	< 0.046	< 0.009
Al	4.84	25.4	11.8	14.8	20.03
As	0.161	0.063	< 0.214	< 0.214	0.17
B	0.282	0.073	0.339	0.286	0.237
Ba	0.064	0.027	< 0.016	< 0.016	0.009
Be	0.033	0.009	0.032	0.03	0.029
Bi	0.286	< 0.023	< 0.208	< 0.208	< 0.067
Ca	461	124	393	487	498.9
Cd	0.083	< 0.009	< 0.042	< 0.038	< 0.027
Cl			94	156	74
Co	0.097	0.522	0.129	0.139	0.224
Cr	0.143	0.038	0.086	0.063	0.083
Cu	0.086	1.09	0.455	0.166	0.637
K			17.4	25.4	11
Mg	85.5	35.3	147	117	114.5
Mn	5.3	2.99	8.01	7.67	8.17
Na	44.9	9.61	5.9	51.1	64.33
Ni	9.79	30.3	19.2	15.9	25.93
P	0.552	0.082	< 0.259	0.304	0.134
Pb	0.341	< 0.049	< 0.496	< 0.496	0.125
Pt	0.53	< 0.073	< 0.734	< 0.734	< 0.147
Rh	< 0.058	< 0.058	< 0.58	< 0.58	0.168
Sb	0.39	< 0.071	< 0.71	< 0.71	< 0.142
Se	0.697	0.103	< 0.82	< 0.82	0.287
Sn	0.092	0.025	< 0.097	< 0.097	0.102
Te	0.63	< 0.095	< 0.95	< 0.95	< 0.191
Ti	0.205	0.009	< 0.03	< 0.03	0.03
V	0.075	< 0.004	< 0.04	< 0.04	0.16
Zn	0.308	0.715	0.571	0.281	0.597
NO3-N	3.5	1.04	3.53	1.71	< 0.1
NO2-N	0.26	0.39			
NH3-N			0.9	2.4	1.9
CO3			< 2	< 2	< 2
SO4 (dis)	3270	1370	3003	2965	5295
Fe (tot)	1300	364	1659	1612	1232
Fe (2+)			597.2	806	147.8
Fe (3+) (calc)			1061.8	806	1084.2

Plate 15. Second pool on pre-bog acid creek.

Plate 16. Third (cattail) pool on pre-bog acid creek with dam on left of photograph and four cattail stands towards right upper corner.

1:2 at the trestle site to 1:1 at the middle pool and then decreases to about 1:7 in the cattail pool.

Elements other than N, S, and Fe: There is considerable variation in elemental concentrations and concentration profiles between the two ends of the pre-bog acid creek in June and September. As expected, the concentrations of metals such as Cr, Ni and Zn are higher in the pre-bog acid creek than in the seepage creek (Tables 20 - 23).

The values in Table 18 compare concetrations which may be useful for comparison as the Levack study progresses, especially following the proposed introduction of semi-aquatic biota, e.g. hydroponically grown cattails and aquatic mosses and an organic layer of refractory material carpeting the bottom of the creek.

General Comment: It is important to note that any organic debris, including small sections of Loofa sponge (mentioned above in Section 3.3.2.) becomes coated with iron precipitate. Similar coatings are observed on the organic matter in the seepage creek. This observation re-confirms the value of physical surfaces on which the iron hydroxide may precipitate from solution. The implication from the seepage creek observations, especially the apparent efficacy of the organic matter in the brome grass pool, as they relate to the techniques which may successfully be applied to the pre-bog acid creek in order to improve water quality are clear. Iron could be removed from the pre-bog acid creek water by introducing refractory organic matter, e.g. cattail leaves. If these leaves accumulate on the bottom of the creek, anaerobic conditions will slowly develop. This may lead to a reduction of SO_4^{-2} and more alkaline pH according to the ideas discussed by King et al., 1974 in their study of coal mine acid drainage.

Hydroponic transplanting: A net with an array of 18 cattails was anchored in the third pond (cattail pond) in the acid creek. The survival of the explants in the arrays will be determined in spring 1986.

The reason for setting up the hydroponic trials with cattail explants was based on well-known ability of plants to grow in soil-less water, e.g. greenhouse tomatoes and other vegetables are frequently grown by this method. Establishing cattails along shorelines or in small streams will aid in mineral removal from the water (Table 18 and Taylor and Crowder, 1983b) and will also begin to build an organic matter layer (of dead cattail leaves and stems) on the bottom of the pond and acid creek. The importance of the accumulation of this organic layer should not be underestimated. King et al. (1974) who studied the recovery of acid strip mine lakes stated that "differences in the rate of accrual of terrestrial organics have a marked effect on the recovery of acid strip mine lakes; those acid lakes with a drainage devoid of vegetation show no recovery after a period of 30 years or more."

3.5. Seepage from Tailings: the Seepage Creek

3.5.1. Site Description and Biota

Table 19 gives a detailed description of the sampling stations at 50 m intervals along the seepage creek. The flow velocity at each of the stations is also given and was generally found to be about 1 ft. sec^{-1} at locations where it was measured.

Although there appears to be one major route of water flow along which the stations were positioned, there are a number of meandering rivulets which diverge from the mainstream and others which join up with it. Some of the latter are relatively major, i.e. the small seep (5) across the road from station VI (see Figure 11). A number of rivulets enter the brome grass pool but there is a broad exit point at station II.

The velocities along the major pathway of the creek are rather uniform, as noted above. Water flow is greatly reduced along the margins of the creek and the hydraulic retention time, i.e. the time required for a water molecule to pass between two horizontal points, is lowest in the brome grass pool compared to other points along the water course, exclusive of small pockets along the creek margin. Plate 17 gives an overview of the physiographic setting of the middle part (stations II to VI) of the seepage creek.

3.5.2. Water Temperature

Water temperature profiles along the seepage creek for the months of July, August, September and November are given in Tables 20, 21, 22 and 23 respectively. Temperatures for August are only slightly higher than those of July. Water emerges from the ground at station VIII at about 18^{o}C and warms up to 20-23^{o}C in July and 22-24^{o}C in August between stations VII and II, and then drops back down to 18.5^{o}C between stations II and I. In September, considerably cooler temperatures prevail, i.e. 7-10^{o}C and in November, there is a temperature gradient between stations VIII (9^{o}C), and II (1.5^{o}C). The stream between stations II and I was frozen in November.

3.5.3. Water pH

Figure 14 shows a rather uniform trend in pH values as one progresses from the head of the seepage creek (Station VIII) to the foot of creek (Station I), just above the area where the water in the creek bed "disappears" into the gravel. Over the first 300 m of the upper creek (stations VIII-III) the pH is uniform, with fluctuations from 5.5 to 6.5 (with the exception of the November sample). There is a steep decline of 2 pH units, i.e. from about 5.9 to 3.9 as the seepage water passes through the brome grass bed, between stations III and II. As noted in Table 19, a web of dead brome grass covered with iron precipitate as well as flocculant suspension of iron precipitate fill the water column within the brome grass bed.

The seepage creek spreads out as it enters the brome grass and flow rate through the brome grass matrix must be reduced. We cannot determine from our data whether it is the increased hydraulic retention time <u>per se</u>, or the decreased water flux coupled with the vast surface area of biomass which

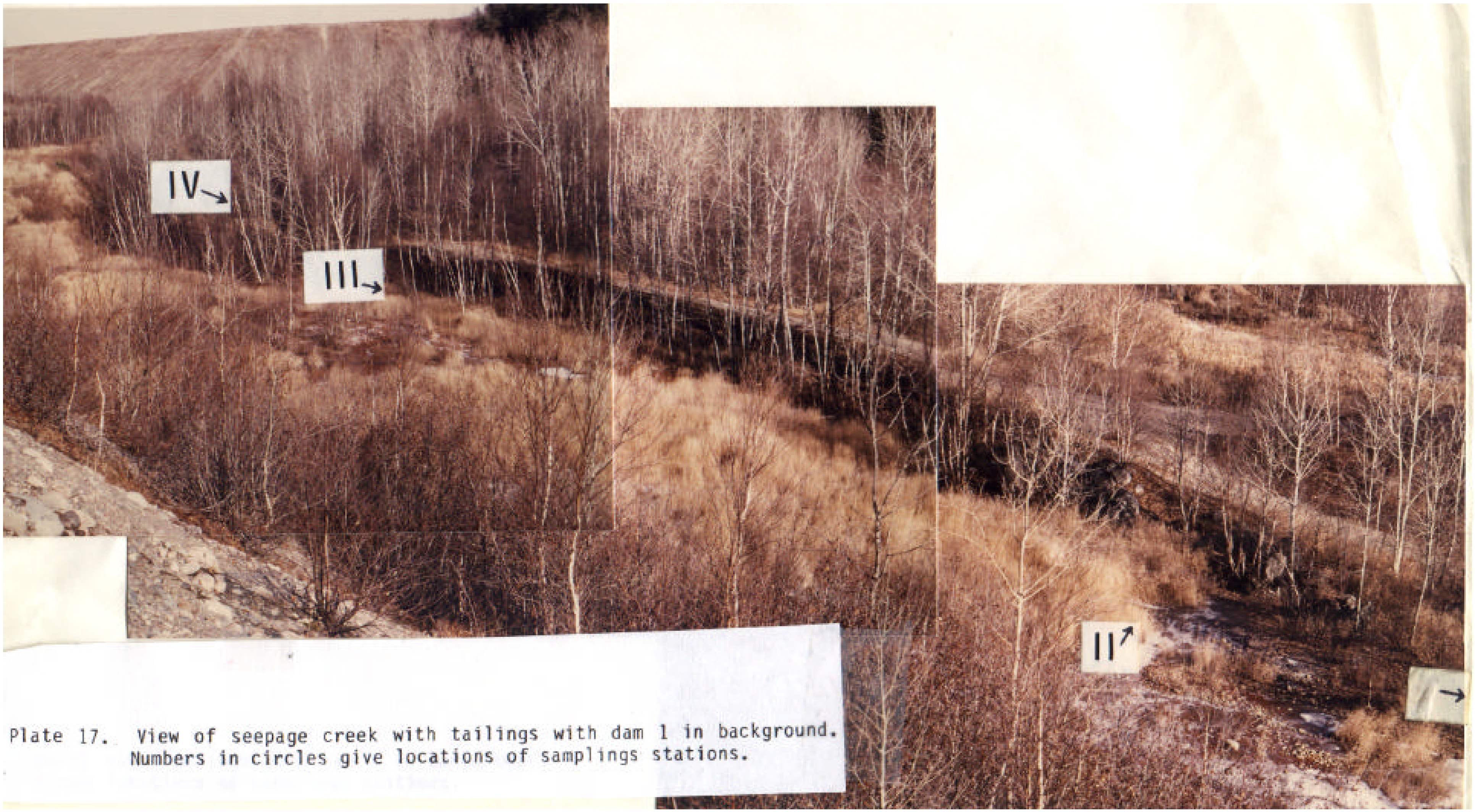


Plate 17. View of seepage creek with tailings with dam 1 in background.
Numbers in circles give locations of samplings stations.

Table 19. Descriptive characteristics of stations from head to foot of the seepage creek.

Station #: IX "acid pool"

Flow Rate (ft/sec): no flow

Station Description:

- very shallow pool with cattails
- very acid (pH 3)
- dominated by *Euglena mutabilis* on silt-like reducing substrate

Station #: VIII "rock pool"

Flow Rate (ft/sec): no flow measured - appears to be an underground spring - possible source of seepage!

Station Description:

- depth in pool about 45-50 cm
- water temperature usually less than other sampling stations
- very little precipitate evident (no orange precipitate): a layer of yellow floc-like precipitate on rocks and debris in pool as well as floating on water surface
- marshy area dominated by cattails and *Equisetum* - shaded area
- microscopically - variety of diatoms and small unicellar algae; no filaments present

Station #: VII "clearing"

Flow Rate (ft/sec): 0.3

Station Description:

- considerable accumulation of precipitate in late June - less precipitate by end of summer with much of the precipitate washed farther downstream (i.e. onto the road); biota dominated by filamentous algal mat consisting of *Ulothrix* - *Microspora* complex; mat responsible for trapping considerable amounts of precipitate; mat consists of layers of (1) green filaments (uncoated with precipitate) growing into flowing waters; (2) older layers with various amounts of precipitate (precipitate accumulation in areas where water flow was reduced or where greater surface area was presented for precipitation
- algal mats were very extensive in late June covering most of the stream channel and holding back water (no flow measurements, however, walking through stream and dislodging algal mats resulted in "gushes" of water and rechannelling of stream
- later in season (August and September), fewer algal mats present at this site, and more defined stream channel with greater flow rate (subjective observation!)

Table 19 continued

Station # VII continued

- microscopically - diverse algal and protozoan community dominated throughout the season by filamentous green algae of the genera Ulothrix, Microspora and Mougestia; a variety of diatoms and unicellular algae also present; occasional filaments of bluegreen algae, e.g. Oscillatoria

Station #: VI "waterfall" (rapids)

Flow rate (ft/sec): 0.95 - about 10 ft (3.5 to 4 m) drop

Station description:

- water flowing over "cliff" - several streams which join below falls to feed main seepage stream
- trees, grass, sticks, etc., in waterfalls
- biota - filamentous green algae on rocks, logs in waterfalls
- microscopically - Ulothrix is dominant species

Station #: V "inflow to pond"

Flowrate (ft/sec): 1

Station description:

- water depth about 5 cm
- stream flowing along road (below waterfalls) above pond on road; gravel from road coated with thin layer of precipitate - little accumulation of precipitate
- biota - grasses, Equisetum, variety of roadside species along stream; filaments of green algae - green with little precipitate accumulation
- microscopically - Ulothrix present, Microspora dominant; a variety of other small algal species evident

Station #: IV "outflow of pond on road"

Flowrate (ft/sec): 1.9

Station description:

- considerable precipitate in stream (precipitate accumulated in the pond on the road over the summer, with very little present in late June but a layer several cm thick by September) - very rapid flow out of pond into stream (Station IV) which flows through a clump of trees into marshy area (Station III)
- biota - no plants or algae in main stream channel - some organic matter accumulation (leaves, sticks, etc.) along edges but rapid flow of stream washes most matter downstream - precipitate, settled on bottom, is not disturbed by rapid water flow

Table 19 continued

Station # IV

- microscopically - small algal species present, no filamentous species noted

Station #: III "birch tree"

Flowrate (ft/sec): 0.25 to 1

Site description:

- relatively rapid flow rate on edge of marshy area; considerable accumulation of orange precipitate (fine silt-like appearance) on bottom of stream forming a relatively undisturbed surface over which water is flowing; sinking depth (into precipitate) variable but usually >10 cm; when disturbed floc-like precipitate is carried downstream
- very little debris in stream
- biota - very little organic matter evident - some leaves, debris, etc., along edge of stream; no algae evident
- microscopically - no filamentous algae; a few small species (flagellates, diatoms, etc.); considerable silt-like precipitate

Station #: II "brome grass area"

Flowrate (ft/sec): < 1 (coming out of grass - marshy area); very little flow evident in marsh

Station description:

- "brome grass" area
- area of tall grasses (e.g. brome grass) which are frequently 1.5 to > 2 m high; considerable accumulation of organic matter - sink 10 to 15 cm into organic layer; considerable iron precipitate evident which is suspended throughout water column and which adheres to submerged plant material; the grass seems to facilitate the precipitation of the iron floc; water is spread out over large area in marshy area so considerable plant surface area is available
- biota - brome grass dominant; other grass species also present; filamentous algae present in channels among grass plants; other species
- mosses, liverworts also present
- microscopically - *Ulothrix microspora* dominant filamentous algae - not as healthy as filaments collected upstream; a variety of small algae (flagellates, diatoms, desmids (a few species) present) - bog-like flora

Table 19 continued

Station #: I "log in stream"

Flowrate (ft/sec): 0.5 (above log); 0.7 (below log)

Station description:

- water flowing over log lying across stream; water depth about 5 cm (above log); very little precipitate evident; accumulations of leaves, sticks, and other organic matter on stream bottom; substrate rocky - stones and large gravel; white precipitate ($Fe(OH)_3$) present on rocks
- biota - filamentous greens (*Ulothrix* and *Microspora*) present; form a black encrustation on rocks; most of this algae dead although some viable filaments
- microscopically - filaments present are composed of dead cells; some viable cells; also several species of small greens (flagellates) and diatoms

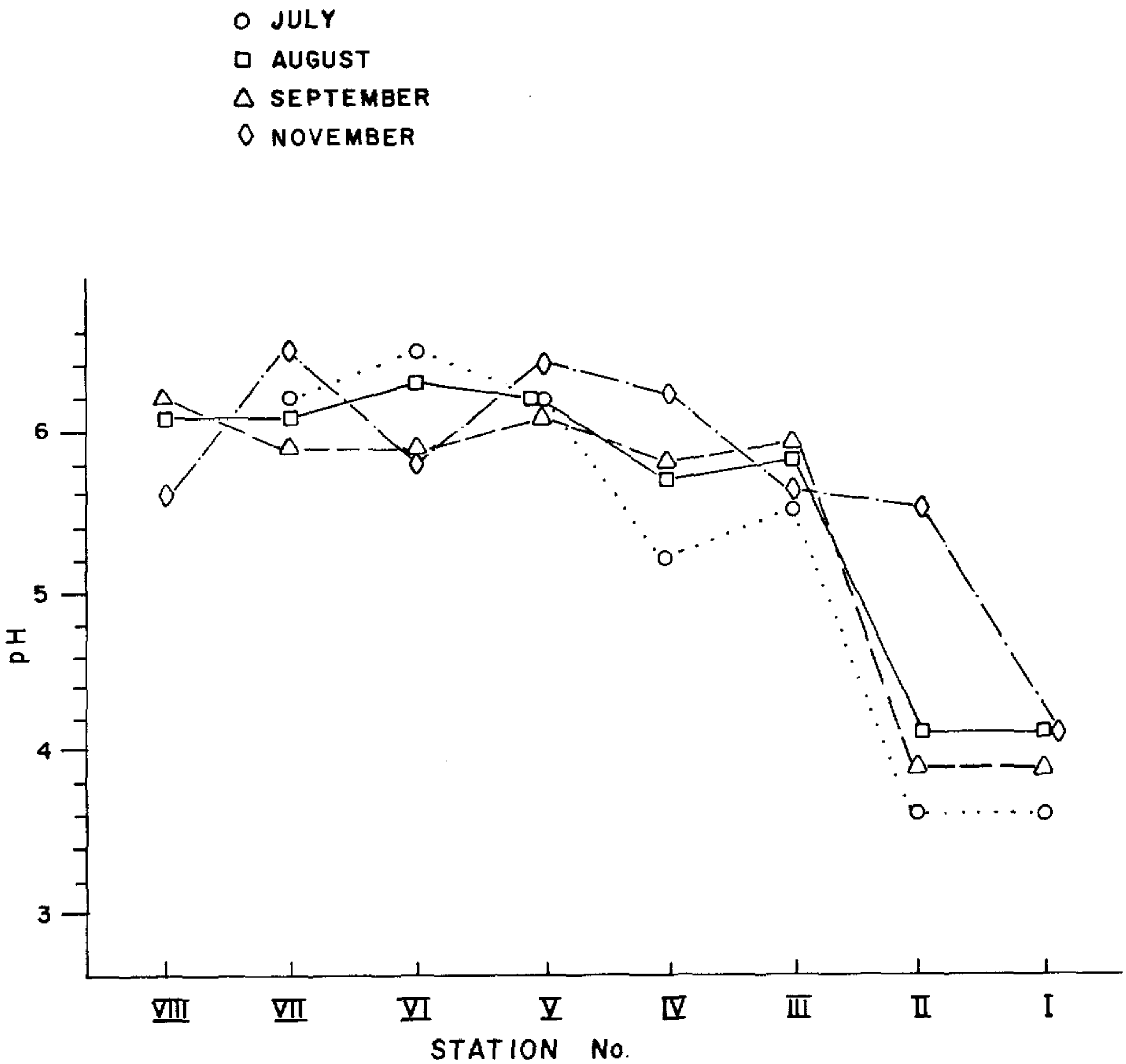


FIGURE 14
SEASONAL CHANGES IN pH AT STATIONS ALONG THE SEEPAGE CREEK

catalizes the hydrolysis of water to form $Fe(OH)_3$ and protons (acidification) (pers. commun. Dr. A. Torma). The dissolution of Ni at stations II and I is most likely a result of this increased acidity.

3.5.4. Water Chemistry

Iron: As Figure 15 shows, iron is the most dynamic element in the seepage creek. The data show a decrease in the concentration of iron in the water over the course of the stream. Some of the samples appear to have been filtered before analysis and this may be the reason for the duplicate of sampling at particular stations. The Fe (total) concentration decreases from 23.5 mg/L to 6.37 mg/L in the apparently filtered samples along the stream. Unfiltered total Fe decreases from 960 to 229 mg/L, indicating removal by precipitation. The decrease in the molar concentration of the soluble iron is from 4.2×10^{-4} to 1.1×10^{-4} moles/L.

At the pH observed in the stream near its headwaters from the ground at Station VII (pH 5.9), the maximum total soluble iron concentration is 3.2×10^{-8} moles/L. Therefore, there is a net supersaturation of the water with iron species at this location. The equilibrium chemistry of the water dictates that the Fe must precipitate as amorphous $Fe(OH)_3$ from the water. This precipitate observed as a reddish-brown sludge, adhered to the bottom of the stream and to the emergent plants which inhabit the stream bed.

Also observed in the stream is the decrease in the pH of the water as it travels along its course. As the pH decreases, the equilibrium concentration of the Fe in the water increases and at some point would be reached, resulting in an end to precipitate production. At the end of the stream, the pH was 3.6 and the Fe concnetration was 1.1×10^{-4} moles/L. The equilibrium concentration at this pH is approximately 1.1×10^{-5}, therefore, the precipitation reaction has not reached equilibrium and would continue if the stream did not re-enter the ground at this point.

The major feature shown in the graph is the slow but steady reduction in total dissolved Fe between stations VIII and III. Total Fe decreases from about 26 ppm to 13 ppm (50%) within 250 m, or a rate of about 0.05 $ppm.m^{-1}$ along the creek. In August, there is an inexplicable dip in Fe at stations V and IV which is not apparent during September. There is a sharp concentration decrease between stations III and II from 13 to 0.2 ppm (August and September values) over a 50 m distance, or a rate decrease of about 0.25 $ppm.m^{-1}$ across the brome grass pool. The dramatic removal of Fe in the brome grass pool is not evident during November. In this month, there is an essential uniform the rate of Fe removal of about 6.7 ppm.50 m^{-1} between stations VI and II.

The supersaturated iron as Fe^{+3} precipitates as ferric hydroxide ($Fe(OH)_3$). The biological material in the stream provides nucleation sites for the accumulation of the precipitate. As the ferric hydroxide precipitates, the solution is left witha surplus of hydrogen ions. The low alkalinity of the water is soon consumed by the hydrogen ion and the pH is depressed. When the soluble iron reaches equilibrium with the water at the final pH, the precipitation reaction ceases and the pH stabilizes. On most days, this occurs just at the point where the stream re-enters the groundwater. Variation in the point at which equilibrium is reached is probably due to differences in the flow rates on different days. Changes in the flow rate will cause changes in the time of travel over the stream and, therefore, the time available for reactions to occur.

It should be re-iterated that the iron and sulfate levels in the seepage creek shown in Tables 20 through 23 are considerably lower than the concentrations in the pre-bog creek (Table 18). Groundwater flowing through pyrrhotitic tailings into the pre-bog acid creek solubilizes, to supersaturation levels, 3 to 5 times more Fe^{+3} and SO_4^{-2} than water arising from the seepage creek. The source of the seepage creek water is still a matter of conjecture at this time.

It is interesting that although the dynamics of total Fe for the months of August and September have essentially similar characteristics over the length of the creek, there is a significant difference between the Fe^{+2}/Fe^{+3} in the two months (Tables 21 and 22). The oxidized iron, Fe^{+3}, is the major soluble constituent during August, while reduced iron, Fe^{+2}, predominates in September. It is possible that the oxidization state of Fe, being greater in August than September, may be related to the relative photosynthetic activity (O_2 production) of algae in the creek. It should be noted that as biological processes, such as photosynthesis, are temperature dependent and therefore have a Q_{10} of about 2, i.e., for a 10^{o} increase in temperature (below the T_{max} for the process) there is a doubling of the process rate, considerable O_2 production may have occurred during August. Fe^{+2} in the water represented an "oxygen sink", where O_2 was consumed in the oxidation of Fe^{+2} to Fe^{+3}. This hypothetical role of aquatic plants in the seepage creek remians to be tested.

It seems unlikely that station IX (see September data in Table 22) is the head of the seepage creek. This site on the seepage creek about 1 m upstream from station VIII, has an exceedingly high Fe^{+2} content of 363 ppm and there is no oxidized Fe. At station VIII, the Fe concentration is reduced by more than an order of magnitude to about 26 ppm. Often in this portion of the creek, there was a very strong smell of sulfur in the air. A similar but less striking concentration reduction was noted for other elements as well (see Table 23).

At present, we are inclined to favour the following two physical factors responsible for the greatest reduction in dissolved iron over the shortest linear distance along the seepage creek. Both factors are present in the brome grass pool: (1) increased hydraulic retention time; and (2) extensive surface area, i.e. the dead brome grass network for adsorption and nucleation of iron hydroxide precipitate.

After the removal of iron by the mechanism(s) described above, it is evident that measures would be required to address the problem of increased acidification created by the iron hydroxide precipitation. Acidification of the water has resulted in an increase in soluble nickel. A wetlands marsh area could be created downstream of the present Station I where water can be retained and not disappear into the gravel. Such a shallow pond, i.e. < 0.5 m deep, filled with semi-aquatic vascular plants and mosses, might function as a passive polishing system to remove Ni. Alternatively, accumulation of organic matter in the bottom of such a pond would gradually result in increased alkalinity and reprecipitation of Ni.

Table 20. Summary of seepage physical-chemical data: July, 1985.

PARAMETER	SAMPLING STATION VII	VI	V	IV	III	II	I
Date - 1985	13/07	13/07	13/07	13/07	13/07	13/07	13/07
Temp (C)	18.5	23	23	20	20	22	18.5
Light	open	shade	open	open	open	open	open
pH	5.9	6.5	6.2	5.2	5.5	3.6	3.6
Cond (umhos/cm)	1500	1600	1700	1500	1500	1550	1400
Hard (mg/L)							
Alkal (tot)							
Tot Solids							
T.S.S.							
Redox (mv)							
D.O. (mg/L)	8.8	10.4	10.2	10.2	9.6	8.6	8.8
Elements (mg/L)							
Ag	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Al	1.16	1.14	15 *	1.39	1.53	1.61	4.25
As	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	0.035
B	0.101	0.135	0.448	0.019	0.069	0.054	0.088
Ba	0.052	0.048	0.09	0.039	0.044	0.056	0.010
Be	b.d.	b.d.	0.02	b.d.	b.d.	b.d.	0.005
Bi	b.d.	b.d.	b.d.	b.d.	b.d.	0.049	b.d.
Ca	317	295	278	298	296	278	286
Cd	0.066	0.005	0.058	0.007	0.004	0.043	0.123
Cl							
Co	b.d.	b.d.	b.d.	b.d.	b.d.	0.007	b.d.
Cr	0.017	0.019	0.127	b.d.	0.013	0.011	0.021
Cu	b.d.	b.d.	b.d.	b.d.	0.067	0.042	0.125
K							
Mg	16.7	16.9	16.8	16.4	16.2	15.9	17.8
Mn	0.923	0.93	1.13	1	1.02	0.978	1.14
Na	105	101	95.6	103	104	93.9	97.8
Ni	<0.018	0.029	0.125	0.049	0.082	0.201	0.4
P	b.d.	0.069	0.409	b.d.	0.034	0.056	0.32
Pb	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	0.219
Pt	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Rh	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Sb	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Se	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Sn	0.013	0.013	0.077	b.d.	b.d.	b.d.	0.012
Te	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Ti	b.d.	0.005	0.156	b.d.	0.007	0.011	0.043
V	b.d.	b.d.	0.035	b.d.	b.d.	b.d.	0.007
Zn	0.078	0.059	0.413	0.017	0.054	0.078	0.149
NO3-N							
NO2-N							
NH3-N							
CO3							
SO4 (dis)							
Fe (tot)	23.5	16.2	875 *	8.23	8.07	6.37	229 *
Fe (2+)							
Fe (3+) (calc)							

* these data are considered abnormally high and were not considered the discussion of seasonal trends

b.d. below detection limits

Table 21. Summary of seepage physical-chemical data: August, 1985.

PARAMETER	VIII	VII	SAMPLING VI	V	STATION IV	III	II	I
Date - 1985	13/08	13/08	13/08	13/08	13/08	13/08	13/08	13/08
Temp (C)	25	24.5	24	24	22	22	20.5	20
Light	shade	open	shade	open	open	open	open	open
pH	6.1	6.1	6.3	6.2	5.7	5.8	4.1	4.1
Cond (umhos/cm)	1250	1300	1350	1350	1350	1400	1450	1400
Hard (mg/L)								
Alkal (tot)								
Tot Solids								
T.S.S.								
Redox (mv)								
D.O. (mg/L)	8.4	8.9	9.8	9.1	8.9	9.2	8.6	8.6
Elements (mg/L)								
Ag	0.007	0.008	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Al	1.88	1.54	1.31	1.45	1.28	1.78	1.36	1.3
As	0.04	0.04	b.d.	0.02	b.d.	b.d.	b.d.	b.d.
B	0.113	0.109	0.108	0.099	0.11	0.096	0.089	0.09
Ba	0.064	0.06	0.053	0.053	0.043	0.05	0.06	0.046
Be	0.001	0.001	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Bi	b.d.	0.05	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Ca	335	338	315	318	312	317	306	279
Cd	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Cl								
Co	0.008	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Cr	0.02	0.019	0.013	0.018	0.01	0.012	0.009	0.009
Cu	b.d.	b.d.	b.d.	b.d.	b.d	b.d	b.d.	b.d.
K								
Mg	18.7	18.1	16.2	16.4	16.6	18	16.6	15.8
Mn	0.99	0.95	0.9	0.92	1.01	1.04	1.02	1
Na	110	109	104	104	106	107	103	93.8
Ni	0.12	0.043	0.037	0.066	0.06	0.072	0.077	0.202
P	0.049	0.04	b.d.	0.026	b.d.	0.045	b.d.	b.d.
Pb	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Pt	0.085	0.086	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Rh	0.107	0.123	b.d.	0.06	b.d.	b.d.	b.d.	b.d.
Sb	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Se	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Sn	0.019	0.023	0.011	0.015	b.d.	0.013	b.d.	b.d.
Te	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Ti	0.051	0.027	0.015	0.017	b.d.	0.04	b.d.	b.d.
V	0.013	0.013	b.d.	0.006	b.d.	b.d.	b.d.	b.d.
Zn	0.175	0.033	0.031	0.033	0.093	0.073	0.081	0.079
NO3-N	0.76	1.63	1.04	0.55	0.56	0.56	1	1.48
NO2-N	0.04	0.05	0.04	0.02	0.02	0.01	0.01	0.01
NH3-N	1.4	1.5	1.4	1.2	1	0.9	0.4	0.5
CO3								
SO4 (dis)	991	1000	982	1040	1078	963	953	866
Fe (tot)	27.2	24.1	19.2	12	8.61	13	1.84	0.233
Fe (2+)	1.2	6.2	4.6	3.1	1.5	< 0.2	< 0.2	< 0.2
Fe (3+) (calc)	26	17.9	14.6	8.9	7.11	12.8	1.64	0.03

b.d. below detection limits

Table 22. Summary of seepage physical-chemical data: September, 1985.

PARAMETER	STATION VIII	VII	VI	V	IV	III	II	I
Date - 1985	12/09	12/09	12/09	12/09	12/09	12/09	12/09	12/09
Temp (C)	9	9	8	11	9	9	11	9
Light	shade	open	shade	open	open	open	open	open
pH	6.2	5.9	5.9	6.1	5.8	5.9	3.9	3.9
Cond (umhos/cm)	1350	1250	1300	1350	1300	1400	1450	1400
Hard (mg/L)	800	800	770	830	900	850	680	740
Alkal (tot)	20	28	18	10	10	10	< 2	< 2
Tot Solids	1648	1616	1586	1632	1568	1818	1436	1548
T.S.S.	31	1	2	8	6	3	1	1
Redox (mv)	230	-227	-233	-238	-224	-222	-119	-113
D.O. (mg/L)	8	8.1	9.2	8.3	8.5	8.7	8.9	8.6
Elements (mg/L)								
Ag	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Al	1.41	0.81	0.83	0.91	1.06	1.02	1.24	1.08
As	b.d.	b.d.	b.d.	0.02	b.d.	0.03	b.d.	b.d.
B	0.04	0.03	0.04	0.05	0.05	0.05	0.31	0.03
Ba	0.06	0.06	0.06	0.06	0.05	0.05	0.06	0.05
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	b.d.	b.d.
Bi	b.d.	b.d.	0.02	b.d.	0.02	b.d.	b.d.	b.d.
Ca	311.7	306.3	311.4	309	302.7	302.7	284.5	283.4
Cd	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Cl	120	115	200	115	180	200	105	105
Co	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	0.009	b.d.
Cr	0.011	0.008	0.008	b.d.	0.007	0.009	0.007	b.d.
Cu	0.022	b.d.	0.007	0.004	0.017	0.01	0.02	b.d.
K	39	37	40	39	40	41	36	36
Mg	16.72	16.01	16.2	16.18	16.34	16.38	16.89	16.24
Mn	0.94	0.9	0.91	0.92	0.99	1	1.18	1.06
Na	114.7	112.6	114.4	113.7	111.1	111	106	104.5
Ni	0.036	0.026	0.038	0.03	0.052	0.063	0.216	0.124
P	0.042	b.d.	b.d.	b.d.	0.032	0.035	b.d.	b.d.
Pb	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Pt	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Rh	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Sb	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Se	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Sn	b.d.	b.d.	b.d.	b.d.	0.01	b.d.	b.d.	b.d.
Te	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Ti	0.06	0.01	0.012	0.015	0.015	0.013	0.011	0.009
V	0.006	0.004	0.005	b.d.	0.006	0.004	b.d.	b.d.
Zn	b.d.	b.d.	0.009	0.013	0.015	0.031	0.024	0.041
NO3-N	< 0.1	< 0.1	0.84	0.2	1.69	< 0.1	3.25	1.75
NO2-N								
NH3-N	1.5	1.4	1.5	1.4	1.3	1.2	0.3	0.7
CO3	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
SO4 (dis)	1155	1117	1117	1155	1059	1059	1059	1117
Fe (tot)	26.19	21.45	20.74	16.89	14.48	13.2	0.746	0.234
Fe (2+)	26.19	13.25	19.9	15	13	10	0.499	0.219
Fe (3+) (calc)		8.2	0.84	1.89	1.48	3.2	0.245	0.015

b.d. below detection limits

Table 23. Summary of seepage physical-chemical data: November, 1985.

PARAMETER	VIII	VII	SAMPLING VI	V	STATION IV	III	II	I
Date - 1985	10/11	10/11	10/11	10/11	10/11	10/11	10/11	10/11
Temp (C)	9	8	7.5	6	6.5	4	1.5	1.5
pH	5.6	6.5	5.8	6.4	6.2	5.6	5.5	4.1
Cond (umhos/cm)	1450	1450	1400	1370	1320	1250	1050	1050
Hard (mg/L)	810	810	790	800	820	790	750	730
Alkal (tot)	24	26	6	10	6	< 2	< 2	< 2
Redox (mv)	-226	-250	-215	-242	-223	-195	-175	-77
Elements (mg/L)								
Ag	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Al	1.15	0.932	1.18	1.05	1.12	1.07	1.25	1.33
As	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
B	0.03	0.05	0.04	0.09	0.03	0.07	0.02	0.03
Ba	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05
Be	<0.001	<0.001	<0.001	<0.001	<0.001	b.d.	b.d.	b.d.
Bi	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Ca	343	332	356	345	327	323	303	303
Cd	b.d.	0.004	0.003	b.d.	b.d.	b.d.	b.d.	b.d.
Cl	110	100	110	105	105	105	95	95
Co	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Cr	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Cu	0.01	0.004	0.027	0.007	b.d.	0.015	0.008	0.027
Mg	17.7	17.2	18	17.4	17.3	17.2	16.8	16.7
Mn	0.99	0.95	1.02	0.97	1.03	1.03	1	1
Na	123	122	126	122	118	117	110	108
Ni	0.024	b.d.	0.027	0.029	0.027	0.031	0.111	0.108
P	b.d.	b.d.	0.042	0.038	b.d.	0.025	b.d.	0.052
Pb	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Pt	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Rh	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Sb	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Se	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Sn	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Te	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Ti	0.021	0.005	0.015	0.01	0.007	0.007	0.007	0.007
V	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.
Zn	0.019	0.017	0.026	0.016	0.022	0.052	0.009	0.051
NO3-N	< 0.01	0.02	0.08	0.04	0.13	0.18	0.39	0.47
NH3-N	1.5	1.6	1.5	1.6	1.3	1.3	0.9	1
Total N	1.51	1.62	1.58	1.64	1.43	1.48	1.29	1.47
CO3								
SO4 (dis)	1117	1078	1155	1117	1155	1059	1001	1290
Fe (tot)	25.1	23.5	28.8	22.6	14.2	8.74	1.77	1.13

b.d. below detection limits

Sulfate: The concentration profiles for SO_4^{-2} along the seepage creek for the three sampling periods show no unifying similarities (Figure 16). The inverse relationship between SO_4^{-2} and Fe in August for the water between stations IV and III is particularly puzzling as the SO_4^{-2} concentration continues to decline between stations III and I in concert with the dramatic drop in the Fe level. A very high level of SO_4^{-2} was recorded at station I in November while Fe was low.

Nitrogen - NO_3^- and NH_4^+: The following important points emerge from the data (Figure 17) for total nitrogen, NH_4^+ and NO_3^- content of the seepage creek water. Firstly, in the upper set of curves for total N, the amount of total N (=NH_4^+ and NO_3^- entering the seepage creek in November is lower than that for August and September. The total N content remains essentially unchanged over the length of the creek during November.

The second important point is that the NH_4^+(=NH_4^+ + NH_3) content at station VIII, where the ground water emerges at the head of the seepage creek, is similar for all three months. It is mainly the variations in the NO_3^- content in the creek which dominates the shape of the total N profile for each month.

The third point, a hypothesis, is that a significant proportion of the NO_3^- in the seepage creek may presumably be derived from microbial nitrification of organically derived N, including free NH_4^+. The NO_3^- level is very low in November because of low water temperatures and hence low Q_{10} for this biological process. Variations in NO_3^- profiles along the creek are an integrated picture of three or more processes occurring at different rates. Such processes include: (1) rate of nitrification (2) NO_3^- uptake by plants and algae in the seepage creek, (3) supplementary additions (or dilutions?) of NO_3^- from tributaries joining the main creek from biologically active pools.

Elements Exclusive of Fe, S and N: Elemental concentrations in seepage creek water were determined in July, August, September and November and are presented in Tables 20, 21, 22 and 23. Generally speaking, in any month, concentrations of any one element are either more or less unchanged over the length of the creek, e.g. Al, K, Mg, Na, Ca; the concentration of an element (in some months) undergoes a net overall decrease between stations VIII and I, e.g. Cr, Cu, P, and Ti. One notable exception however is Ni, and to a lesser extent, Zn.

While the concentration of Ni remains relatively unchanged (between 0.025 and 0.05 ppm) in waters between stations VII and IV, there is a dramatic increase in Ni content to 0.1 - 0.2 ppm at Stations II and I.

Special note should be made at the initially high (maximum) concentrations of nearly all of the elements at station VIII at the head of the seepage creek. Again, Ni is an exception. The concentration of Ni at this station is 0.12, 0.04 and 0.024 ppm in August, September and November, respectively, and increases to 0.1 and 0.2 at Station I.

The dissolution of Ni (and Zn) is probably due to acidification occurring between Stations VI and I. As discussed in the section on pH, the acidification of the acid creek, especially marked between Stations III and I - the brome grass pool - is best explained by iron hydroxide formation (and precipitation) and concomitant H^+ production during hydrolysis of H_2O.

3.5.5. Algae and sediment analyses

Filamentous alga, Ulothrix: Table 24 (upper portion) gives the Fe, S, Cu, Ni and Zn content of Ulothrix collected from several stations in September. It must be emphasized at the outset, that although the algal filaments in the "clean" samples were devoid of visible traces of particulate matter, it is possible that microlayer of Fe and co-precipitated ions could have been adsorbed onto the surface of the algal filaments (Plate 18).

As the chemical behaviour of Ni and Zn are similar to iron, the high background level of Fe made it exceedingly difficult to obtain reliable numbers for Ni and Zn concentrations by ICP and AA spectroscopic procedures. Dilutions of aqueous preparations in order to reduce Fe interference increased the lower limit of detection of Ni and Zn (and other metals as well).

The main point shown in the Table 24 is that there is a higher Fe content associated with Ulothrix from Station VII than stations II and I. Although this result may be directly correlated with the amount of iron in the seepage creek at these stations (see Figure 15), it does not favour either of the possible roles of the Ulothrix in the seepage creek, i.e. that of actively absorbing Fe (a physiological process) vs. passively adsorbing Fe (a physical-chemical process). In the latter case, an iron precipitate also seemed to be associated with fibers of glass wool which were placed in the seepage creek at stations VII and III. However, it was not possible to decide whether the particulate matter associated with the glass wool fibers had actually formed on the fiber surface or had been passively trapped by the fibers as the particles were moving downstream.

Precipitate: The lower half of Table 24 shows the chemical data for the precipitate collected at various stations in the seepage creek, beginning with station IX. As we have noted before however, this station is probably not the start of the creek although it is within 1 m of station VIII. The precipitate at both stations IX and VIII was a flocculant material, grey in colour rather than orange-brown. The lowest Fe values for any of the stations were found here, while levels of Cu, Ni, and Zn are high. Over the remaining length of the creek the Fe values range between 338 and 407 x 10^6 ppm, except for station IV (176 x 10^3 ppm). This may be explained by the fact that the sample from this latter, rapidly flowing portion of the seepage creek probably contained a large percentage of non-ferrous sand-like particles of heavier mass which sedimented out in the stream. Most of the precipitate would have been retained in the water column at this station.

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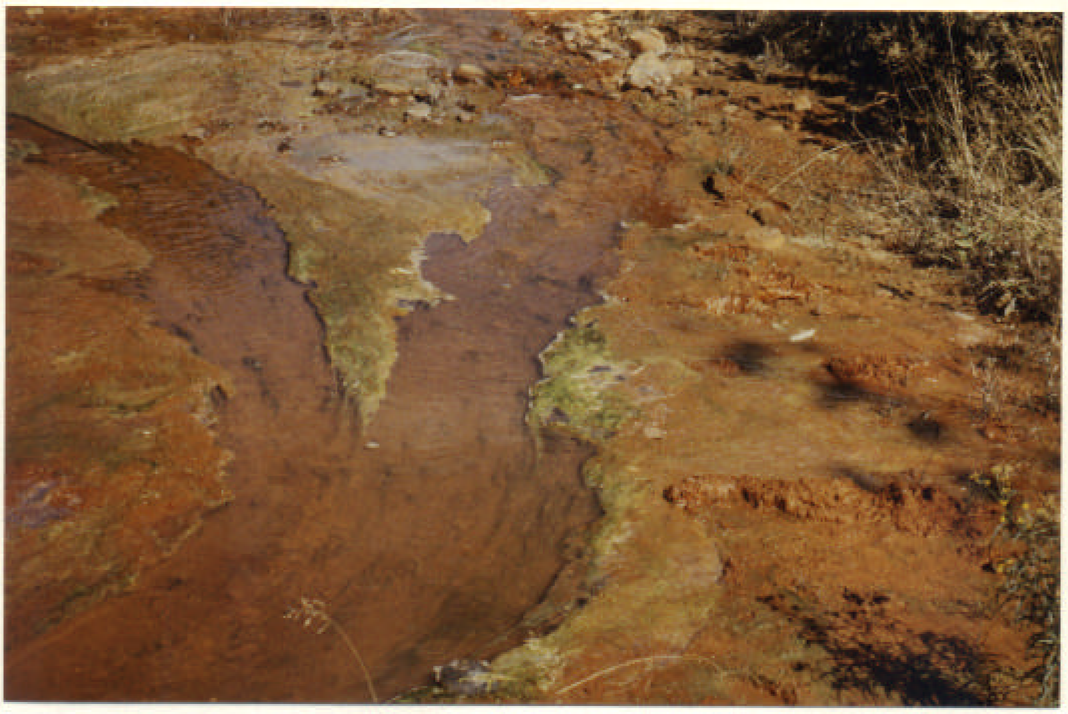

Plate 18. Seepage creek station VII showing densely layered Ulothrix along the margins of the creek channel. Note iron hydroxide precipitate trapped in the algal mat.

Table 24. Fe,S,Cu, No and Zn content of Ulothrix and precipitate from the seepage creek.

STATION	SAMPLE DES.	Fe	S	Cu	Ni	Zn
		ug/g				
VII	clean	287,440	8,661	203	45	70
VII	washed	220,600	4,333	211	20	65
VII	Older mat	333,160	10,276	205	40	190
VII	inner edge of mat	345,180	6,419	172	55	70
VII	Clean	281,400	5,244	310	5	70
II	Washed	124,096	4,991	<5.6	130	90
I	Washed	185,458	7,026	<5.6	15	90
IA	Algae and leaf litter	23,136	6,849	<5.6	250	75
IX	precipitate	113,364	9,645	882	182	10.2
VIII		141,348	8,581	414	<36	<9.4
VII		407,140	4,657	<5.6	<36	<9.4
V		338,000	11,153	<5.6	<36	<9.4
IV		176,088	1,108	<11.2	<72	<18.8
III		388,160	13,455	<5.6	<36	<9.4
I		406,620	16,057	<5.6	<36	<9.4

4.0. CONCLUSIONS AND RECOMMENDATIONS

In 1985, the basic requirement of ecological engineering had to be demonstrated namely that suitable indigenous species can be introduced and promoted at Levack. Furthermore, data to establish suitable experimental areas had to be set up in order that the overall objectives could be addressed in 1986.

It can be concluded from the 1985 work that the possibility of sealing pyrrhotite surfaces by distribution of alkaline waste waters over these surfaces appears to be a promising method for close-out. Furthermore, promoting vegetation covers for organic matter production on top of the newly deposited alkaline mine slimes seems feasible. Rudimentary cattail stands may be effectively expanded over areas covered with waste water (acid or alkaline) if the root -rhizome expansion and the transplant experiments yield good results in 1986.

From the work on the seepage leaving the tailings area and the extreme conditions of on the surface waters on the pyrrhotite tailings, both of which present extreme chemical conditions, it can be concluded that iron can be removed on precipitation sites provided by tolerant biota. The observations and results indicate clearly that the presence and accumulation of organic matter lead to the improvement of water quality. The development of biological polishing systems is suggested as an approach to treatment of seepages and extreme acid/sulphate/iron waters on tailings.

In dry areas of acid generating tailings, the investigation of literature suggested that a moss cover may be more beneficial in reducing the oxidation of tailings, given the physical characteristics of the root zones of vascular plants. Experiments of direct moss cover development yielded promising results on alkaline surfaces, however further experiments are needed for the acidic conditions.

Results from the over-wintering experiments are still wanting at present and therefore conclusions are not warranted on many aspects of the work at Levack. However the experiments started in 1985 indicate that for close-out, several principal areas could be pursued with good indication of yielding promising results. These areas address the overall objective set at the onset of the program, which is to develop Ecological Engineering methods for the wide variety of conditions present on the Levack site, which would lead to an improvement in water quality.

5.0. REFERENCES

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6.0. APPENDIX

Station # I

Cover	Quadrat #1 July	Quadrat #1 Aug	Quadrat #1 Sept	Quadrat #2 July	Quadrat #2 Aug	Quadrat #2 Sept	Quadrat #3 July	Quadrat #3 Aug	Quadrat #3 Sept	Quadrat #4 July	Quadrat #4 Aug	Quadrat #4 Sept	Quadrat #5 July	Quadrat #5 Aug	Quadrat #5 Sept	Quadrat # July	Quadrat # Aug	Quadrat # Sept
Bare tailings	100	100	100	100	100	100	20	15	65	80	85	65	90	65	75	95	95	100
Algae																		
Moss (protonemata)																		
(mature)																		
Equisetum														5		5	<1	
Grass										(rye?) 20	<1		(rye?) 5	20		(Rye?) 1	<1	
Redtop grass											(purple top) 5	25			<1			
Aspen (seedlings)																		
Sorrel (seedlings)																		
(mature-veg.)					<1										<1			
(" fruiting)																		
Cattail (seedlings)																		
(mature)	<1						60	35	35	6	5	10	10		25			
Mulch (straw)																		
(cotton, paper straw)																		
Litter (cattail)							20	40						35				
(plant)																2		

All quadrats under water in July

½ cattails were fruiting

Station ~~I~~ #II

Cover	Quadrat #1 July	Quadrat #1 Aug	Quadrat #1 Sept	Quadrat #2 July	Quadrat #2 Aug	Quadrat #2 Sept	Quadrat #3 July	Quadrat #3 Aug	Quadrat #3 Sept	Quadrat #4 July	Quadrat #4 Aug	Quadrat #4 Sept	Quadrat #5 July	Quadrat #5 Aug	Quadrat #5 Sept	Quadrat #6 July	Quadrat #6 Aug	Quadrat #6 Sept
Bare tailings	60	40	45	98	100	~~100~~ 98	100	~~15~~ 100	96	90	90	98	100	100	99	100	100	100
Algae																		
Moss (protonemata)																		
(mature)																		
Equisetum	40	60	50															
Grass								<1			<1					<1	<1	
Red top grass												<1						<1
Aspen (seedlings)									5									
Sorrel (seedlings)																		
(mature-veg.)						1			<1	5	5	2		<1	1			
(" fruiting)																		
Cattail (seedlings)																		
(mature)	9	5	5	4	<2	1		~~35~~		8	8	10						
Mulch (straw)																		
(cotton, paper straw)																		
Litter (cattail)								~~70~~										
(plant)										2								

Qudrats 1-4 under water

Station # III

Cover	Quadrat # 1 July	Quadrat # 1 Aug	Quadrat # 1 Sept	Quadrat # 2 July	Quadrat # 2 Aug	Quadrat # 2 Sept	Quadrat # 3 July	Quadrat # 3 Aug	Quadrat # 3 Sept	Quadrat # 4 July	Quadrat # 4 Aug	Quadrat # 4 Sept	Quadrat # 5 July	Quadrat # 5 Aug	Quadrat # 5 Sept	Quadrat # 6 July	Quadrat # 6 Aug	Quadrat # 6 Sept
Bare tailings	100	100	98	50	45	~~90~~ 40	70	50	70	65	40	70	65	70	50	85	50	85
Algae																		
Moss (protonemata)						1												
(mature)		10		50	70*		35*	35**		*25	*42**		*35	*40			*35	
Equisetum											<1		2	10	<1	15	8	10
Grass				5	5		<1	<1										
Redtop grass																		
Aspen (seedlings)																		
Sorel (seedlings)	2		2															
(mature-veg.)	[illegible]																	
(" fruiting)																		
Cattail (seedlings)																		
(mature)			<1			<1												
Mulch (straw)				50	50	100		<10			10			2		5	5	5
(cotton, paper straw)				~~50~~			10		30	35		30	10		60			
Litter (cattail)																		
(plant)																		

Quadrat # 2: * 40% under straw; 30% ~~under mulch~~ open sun

Quadrat # 3: * 5% under mulch; 30% open sun; ~~** 30% open sun~~; ** 7 open sun

Quadrat # 4: * open sun; ** 37% open sun, 5% under straw

Quadrat # 5: * open sun; ~~** 40% open sun~~

Quadrat # 6: * open sun

Station #IV

Cover	Quadrat #1 July	Quadrat #1 Aug	Quadrat #1 Sept	Quadrat #2 July	Quadrat #2 Aug	Quadrat #2 Sept	Quadrat #3 July	Quadrat #3 Aug	Quadrat #3 Sept	Quadrat #4 July	Quadrat #4 Aug	Quadrat #4 Sept	Quadrat #5 July	Quadrat #5 Aug	Quadrat #5 Sept	Quadrat #6 July	Quadrat #6 Aug	Quadrat #6 Sept
Bare tailings	95	75	99	100	100	100	100	100	100	85	80	65	70	70	70	100	90	95
Algae																		
Moss (protonemata)																		
(mature)		*45	1		5	1		[illegible]	<1		*40	*35	10	*25	30	<1	2	*5
Equisetum																		
Grass		<1			<1			<1	<1		<1	5	10	<1	<1		<1	2
Redtop grass										<1						<1		
Aspen (seedlings)																		
Sorel (seedlings)																		
(mature veg.)												<1						<1
(" fruiting)																		
Cattail (seedlings)																	<1	<1
(mature)																		
Mulch (straw)	5	<1	1			1		<1		15	3	8	10	10				
(cotton, paper straw)															5			
Litter (cattail)																		
(plant)																		

* open sun (Quadrat #1) · * open sun (Quadrat #4) · * open sun (Quadrat #5) · * open sun (Quadrat #6)

Cover	Station #V Quadrat #1 July	Aug	Sept	Quadrat #2 July	Aug	Sept	Quadrat #3 July	Aug	Sept	Quadrat #4 July	Aug	Sept	Quadrat #5 July	Aug	Sept	Quadrat #6 July	Aug	Sept
Bare tailings	100	80	50	100	95	80	99	85	95	99	90	30	100	95	80	100	90	~~80~~ 95
Algae																		
Moss (protonemata)																		
(mature)		30	50		5	20		20	5		20	70		10	20		15	
Equisetum									<1				<1				2	2
Grass		4	<1	<1	<1	5		<1	2								<1	
Redtop grass																		
Aspen (seedlings)																		
Sorel (seedlings)																		
(mature-veg.)				<1			<1			<1				<1	2		1	<1
(" fruiting)																		
Cattail (seedlings)							1	<1		1	1	2		<1	<1			<1
(mature)																		
Mulch (straw)																		
(cotton, paper straw)							1	5										
Litter (cattail)																		
(plant)																		

Station # VI

Cover	Quadrat # 1 July	Aug	Sept	Quadrat # 2 July	Aug	Sept	Quadrat # 3 July	Aug	Sept	Quadrat # 4 July	Aug	Sept	Quadrat # 5 July	Aug	Sept	Quadrat # 6 July	Aug	Sept
Bare tailings	95	100	100	65	60	95	25	40	95	20	20	65	95	90	99	100	99	100
Algae																		
Moss (protonemata)																		
(mature)	<1	*2		10	*15		<1	*40		40								
Equisetum																		
Grass					<1	<5		5	5	<1	5	2						
Redtop grass																		
Aspen (seedlings)																		
Sorrel (seedlings)																	2	
(mature veg.)					<1	<1				5		*40	5	5	*5		*2	<1
(" fruiting)										5	20							
Cattail (seedlings)																		
(mature)																		
Mulch (straw)	5	<1		25	5		75	60		80	70		<1					
(cotton, paper straw)					35													
Litter (cattail)																		
(plant)																		
	*open sun			*5% undercover 10% in sun			*30% undercover 10% in sun			*90% dead			*all dead					

Station # VII

COVER	Quadrat # 1 July	Aug	Sept	Quadrat # 2 July	Aug	Sept	Quadrat # 3 July	Aug	Sept	Quadrat # 4 July	Aug	Sept	Quadrat # 5 July	Aug	Sept	Quadrat # 6 July	Aug	Sept
Bare tailings	75	95	90	50	100	100	80	90	70 ~~100~~	100	*50	100	100	100	100	100	100	100
Algae																		
Moss (protonemata)																		
(mature)	<1			<1			<1											
Equisetum																		
Grass																		
Red top grass																		
Aspen (seedlings)																		
Sorel (seedlings)	5	~~10~~		50			5											
(mature-veg.)	20	~~1~~	*15					2					<1					
(" flowering/fruiting)		10		1			5											
Cattail (seedlings)																		
(mature)				5			10	5	30									
Mulch (straw)																		
(cotton, paper straw)																		
Litter (cattail)								5										
(plant)																		

* all dead

* additional 50% open water

Station # VIII

Cover	Quadrat # 1 July	Aug	Sept	Quadrat # 2 July	Aug	Sept	Quadrat # 3 July	Aug	Sept	Quadrat # 4 July	Aug	Sept	Quadrat # 5 July	Aug	Sept	Quadrat # 6 July	Aug	Sept
Bare tailings	90 ~~95~~	100	*100	75	60*	100	25	70	100	~~[illegible]~~ 100	100	95	~~40~~ 100	95	80	100	95	90
Algae																		
Moss (sectonmata)																		
(mature)	<1 ~~<1~~			10			5							5			6	
Equisetum																		
Grass								<1										
Red top grass																		
Aspen (seedlings)																		
Sorel (seedlings)																		
(mature veg.)	~~36~~	<1													*15			
(" fruiting)	1 ~~1~~																	
Cattail (seedlings)																		
(mature)																		
Mulch (straw)	10			25	5		5					5			20			
(cotton, paper straw)							65	30										10
Litter (cattail)																		
(plant)																		

* flooded — Quadrats 1-6

* plus 40% open water

* all dead

Station # IX

Cover	Quadrat # 1 July	Aug	Sept	Quadrat # 2 July	Aug	Sept	Quadrat # 3 July	Aug	Sept	Quadrat # 4 July	Aug	Sept	Quadrat # 5 July	Aug	Sept	Quadrat # 6 July	Aug	Sept
Bare tailings	70	90	*100	5	10	100	90	60	100	>90	70	100	99	85	100	100	100	100
Algae																		
Moss (protonemata)																		
(mature)	<2	*2		90	*90			40		5	30		1	80			<1	
Equisetum																		
Grass		5																
Redtop grass					2													
Aspen (seedlings)																		
Sorel (seedlings)																		
(mature-veg.)							1	10			5							
(" fruiting)							<1			1								
Cattail (seedlings)							2											
(mature)										2								
Mulch (straw)	15	5		95	90													
(cotton, paper straw)	5																	
Litter (cattail)																		
(plant)																		

*open sun

*Eroded quadrats 1-6

*85% under cover

Station # ~~II~~ X

COVER	Quadrat #1 July	Aug	Sept	Quadrat #2 July	Aug	Sept	Quadrat #3 July	Aug	Sept	Quadrat #4 July	Aug	Sept	Quadrat #5 July	Aug	Sept	Quadrat #6 July	Aug	Sept
Bare tailings	100	100	*100	100	100	100	99	100	100	100	100	100	75	95	100	20	15	100
Algae																		
Moss (protonemata)																		
(mature)		<1			<1		1	5			<5		<1	10			*85	
Equisetum																		
Grass																		
Red top grass																		
Aspen (seedlings)																		
Sorel (seedlings)																		
(mature-veg.)																		
(" fruiting)																		
Cattail (seedlings)					<1								1	5		2		
(mature)													*(15)	3			1	
Mulch (straw)																70	85	
(cotton, paper straw)																		
Litter (cattail)																		
(plant)													10	2		5		

\# flooded quadrats 1-4

* young

* 80 moss under cover.

Station # XI

Cover	Quadrat #1 July	Quadrat #1 Aug	Quadrat #1 Sept	Quadrat #2 July	Quadrat #2 Aug	Quadrat #2 Sept	Quadrat #3 July	Quadrat #3 Aug	Quadrat #3 Sept	Quadrat #4 July	Quadrat #4 Aug	Quadrat #4 Sept	Quadrat #5 July	Quadrat #5 Aug	Quadrat #5 Sept	Quadrat #6 July	Quadrat #6 Aug	Quadrat #6 Sept
Bare tailings	100	100	*100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Algae																		
Moss (protonemata)																		
(mature)		5			<5			5			<1		<1	2			2	
Equisetum																		
Grass																		
Red top grass																		
Aspen (seedlings)																		
Sorel (seedlings)																		
(mature veg.)																		
(" fruiting)																		
Cattail (seedlings)					<1												1	
(mature)																		
Mulch (straw)																		
(cotton, paper straw)																		
Litter (cattail)																		
(plant)																		

* flooded quadrats 1-6

Station # XII

COVER	Quadrat # 1 JULY	AUG	SEPT	Quadrat # 2 JULY	AUG	SEPT	Quadrat # 3 JULY	AUG	SEPT	Quadrat # 4 July	AUG	SEPT	Quadrat # 5 July	AUG	SEPT	Quadrat # 6 July	AUG	SEPT
Bare tailings	95	95	>95	100	95	* 95	100	100	95	100	100	100	100	100	100	100	100	90
Algae																		
Moss (protonemata)																		
(mature)		*5		<1	5	**5		<1	5		<1			<1		<1	5	10
Equisetum																		
Grass		5	<5															
Redtop grass	<1																	
Aspen (seedlings)																		
Sorrel (seedlings)																		
(mature-veg.)																		
(" fruiting)																		
Cattail (seedlings)																		
(mature)																		
Mulch (straw)	5																	
(cotton, paper straw)																		
Litter (cattail)																		
(plant)																		

* open sun

* flooded Quadrats 2-5
** open sun

Station # XIII

COVER	Quadrat #1 July	Quadrat #1 Aug	Quadrat #1 Sept	Quadrat #2 July	Quadrat #2 Aug	Quadrat #2 Sept	Quadrat #3 July	Quadrat #3 Aug	Quadrat #3 Sept	Quadrat #4 July	Quadrat #4 Aug	Quadrat #4 Sept	Quadrat #5 July	Quadrat #5 Aug	Quadrat #5 Sept	Quadrat #6 July	Quadrat #6 Aug	Quadrat #6 Sept
Bare tailings	100	>95	90	80	50	90	87	40	50	90	50	50	75	60	45	75	40	10
Algae																		
Moss (protonema)																		
(mature)		<5*	10	15	50	70	<1	*5	40	<1	30	50		20	20	<1	20	80
Equisetum																		
Grass																		
Red top grass																		
Aspen (seedlings)																		
Sorel (seedlings)								1										
(mature-veg.)								5	<1			10	5	2	*10			
(" fruiting)																		
Cattail (seedlings)					<1					<1			20	2		25		
(mature)				5	<5	7	3	10	9								<1	
Mulch (straw)								30			30			25			40	
(cotton, paper straw)							10			10		<1		~~25~~			~~40~~	
Litter (cattail)					<1			5										
(plant)			4						5						5			

* open sun (Quadrat #1)

* open sun (Quadrat #3)

* dying (Quadrat #5)

Station # ~~X~~ XV

Cover	Quadrat #1 July	Quadrat #1 Aug	Quadrat #1 Sept	Quadrat #2 July	Quadrat #2 Aug	Quadrat #2 Sept	Quadrat #3 July	Quadrat #3 Aug	Quadrat #3 Sept	Quadrat #4 July	Quadrat #4 Aug	Quadrat #4 Sept	Quadrat #5 July	Quadrat #5 Aug	Quadrat #5 Sept	Quadrat #6 July	Quadrat #6 Aug	Quadrat #6 Sept
Bare tailings	20	10	~~90~~ 85	100	100	90	100	100	100	100	100	85	85	90	60	100	100	75
Algae																		
Moss (protonemata)																		
(mature)	5	*20	**40 ~~10~~			*10		<2	<1		<1	*15		10	*40		<1	*25
Equisetum																		
Grass		<1																
Red top grass																		
Aspen (seedlings)																		
Sorel (seedlings)																		
(mature veg.)																		<1
(" fruiting)																		
Cattail (seedlings)	15												15					
(mature)									1									
Mulch (straw)	80	80												5	<1			<1
(cotton, paper straw)																		
Litter (cattail)																		
(plant)			~~<1~~ 50									<1						

Quadrat #1: * 10% under sun

10% under cover

**~~20~~ 25% open sun

* 15% under straw

Quadrat #2: * open sun

Quadrat #4: * open sun

Quadrat #5: * open sun

Quadrat #6: * open sun

Station # ~~XV~~

Cover	Quadrat #1 July	Aug	Sept	Quadrat #2 July	Aug	Sept	Quadrat #3 July	Aug	Sept	Quadrat #4 July	Aug	Sept	Quadrat #5 July	Aug	Sept	Quadrat #6 July	Aug	Sept
Bare tailings	55	40	50	70	50	~~90~~ 20	5	20	30	25	15	20	50	40	40	25	40	40
Algae																		
Moss (protonemata)																		
(mature)		*49	50		*30	**70		** ~~65~~ 40	***10	** ~~65~~ 40	**80	***80		**50	***60		** 35	***60
Equisetum																		
Grass						<1		<1										
Redtop grass																		
Aspen (seedlings)																		
Sorrel (seedlings)							[illegible]											
(mature-veg.)		3	4					<1			<1							
(" fruiting)																		
Cattail (seedlings)	*45			30	<1		*95		<1	*65		<1	*50			*75		<1
(mature)																		
Mulch (straw)		20	5		20			70	30			50		15			~~15~~ 50	
(cotton, paper straw)											65							
Litter (cattail)		[illegible]																
(plant)						50				10	5							

Quadrat #1: *35% under straw; *open sun-45%, 2% under straw

Quadrat #2: *open sun - 30%, 5% under straw; ** 30% open sun, 40% under straw

Quadrat #3: * 40% under straw; ** 30% under sun, 30% under straw; *** 45% open sun, 4% under straw

Quadrat #4: * 45% under straw; ** under straw; *** 60% under straw, 30% under sun; **** 1/2 under straw, 1/2 under sun

Quadrat #5: * 35% under straw; ** 40% under straw, 10% under sun; *** 1/2 under straw, 1/2 open sun

Quadrat #6: * 15% under straw, 60% under sun; ** 25% under cover; *** 50% open sun, 10% under straw

Station # XVI

COVER	Quadrat # 1 July	Quadrat # 1 Aug	Quadrat # 1 Sept	Quadrat # 2 July	Quadrat # 2 Aug	Quadrat # 2 Sept	Quadrat # 3 July	Quadrat # 3 Aug	Quadrat # 3 Sept	Quadrat # 4 July	Quadrat # 4 Aug	Quadrat # 4 Sept	Quadrat # 5 July	Quadrat # 5 Aug	Quadrat # 5 Sept	Quadrat # 6 July	Quadrat # 6 Aug	Quadrat # 6 Sept
Bare tailings	10	15	20	80	65	95	65	65	80	83	40	60	55	20	40	45	10	55
Algae																		
Moss (protonemata)		~~**75~~																
(mature)		**75	.5	*20	**25		*32 →	→	**5		*25	**40		*80	#40*		*75	
Equisetum									1						<1			
Grass		<1	1		<1		<1 →	→			<2						<1	
Red top grass																		
Aspen (seedlings)																		
Sorel (seedlings)							←	<1	1	16			15			5		
(mature-veg.)		5									10			2	<1			
(" fruiting)														3				
Cattail (seedlings)	*90						←	35		2		5	30			40		40
(mature)																		
Mulch (straw)		85			20		5 →	→	10		10	25		1			~~15~~	
(cotton, aspen straw)													1			10	15	
Litter (cattail)			75															
(plant)						1												5

Quadrat # 1: * 85% under straw; ** 65% under cover

Quadrat # 2: * under straw; ** 10% under straw

Quadrat # 3: * 30% under sun, 2% under straw; ** open sun

Quadrat # 4: * 20% open sun, 5% under straw; ** ½ under sun, ½ under straw

Quadrat # 5: * open sun

Quadrat # 6: * 70 open sun, 5% under straw

Station # XVIII

Cover	Quadrat # 1 July	Aug	Sept	Quadrat # 2 July	Aug	Sept	Quadrat # 3 July	Aug	Sept	Quadrat # 4 July	Aug	Sept	Quadrat # 5 July	Aug	Sept	Quadrat # 6 July	Aug	Sept
Bare tailings	60	90	75	~~3~~5	35	95	10	5	50	7	5	20	7	10	50	85	70	50
Algae																		
Moss (protonemata)																		
(mature)		*5		**30	***40	**10		*40	**20	<1	**77	*30		*30	5	5	*30	*40
Equisetum	<1		20			4			<1					1	2			4
Grass		<1						2	5		<1	2						
Redtop grass																		
Aspen (seedlings)																		
Sorel (seedlings)	5			5			10						5					
(mature-veg.)														10				
(" fruiting)																		
Cattail (seedlings)	35			*20			40		2	*90		2	30		<1	5		5
(mature)							<1	2		3	4	4	8	10		1	1	3
Mulch (straw)				~~55~~	35	25		5			95	60						
(cotton, paper straw)																		
Litter (cattail)								60	30		2			40	30			
(plant)		5	5				40	10					50			5		5

Quadrat # 1: * open sun

Quadrat # 2: * under straw; ** open sun; *** 30% open sun 10% under straw

Quadrat # 3: * 30 under sun 10 under straw; ** under sun

Quadrat # 4: * under straw; ** 70% under sun 2% under straw

Quadrat # 5: * 20 under sun 10 under straw

Quadrat # 6: * open sun

Station # XIX

COVER	Quadrat # 1 July	Aug	Sept	Quadrat # July	Aug	Sept	Quadrat # July	Aug	Sept	Quadrat # July	Aug	Sept	Quadrat # July	Aug	Sept	Quadrat # July	Aug	Sept
Bare tailings	98	100	95															
Algae																		
Moss (protonemata)																		
(mature)			*5															
Equisetum		[illegible]																
Grass		<1	4															
Red top grass																		
Aspen (seedlings)																		
Sorel (seedlings)																		
(mature-veg.)																		
(" fruiting)																		
Cattail (seedlings)																		
(mature)																		
Mulch (straw)																		
(cotton, paper straw)	2																	
Litter (cattail)																		
(plant)																		

*underseen

6.2. Hydrological Reconnaissance: Area Water Balance Requirements

Information on the hydrogeology of the area is limited. A study carried out by International Water Supply in 1969 addressed water requirements for the townsite and the mill. However, it does not provide information on the hydrogeological conditions in the vicinity of the tailings area. Several piezometers were found in the vicinity of the seepage creek to the south of the main dam. However, no information on their origin or purpose was available.

The overall water balance of the area is important for determining the need to augment the water supply for close-out the optimum case is that the area will be self-sufficient in water. To determine this, the section below identified the measurements which would be required to assess the incident precipitation and run-off water in the area.

Area Water Balance Data Requirements

The data gathering program will include the following components for the determination of the overall basin water balance:

- the installation of a recording rain gauge on the site;
- the installation of a flume on the seepage located south of Dam 1 to measure the flow exiting the basin via that route;
- the instigation of a flow recording program for the input to the area from the tailings line; this will be carried out in co-operation with INCO staff who will be asked to maintain detailed records of pump on times, etc.;
- the installation of a flow measuring device in the decant structure; this may not be required if the re-cycle rate to the mine can be determined with accuracy;
- a snow survey of the tailings surface and surrounding watershed at the time of installation of the precipitation gauge.

These measures must be carried out early in the year so that the volume of water available from the spring runoff can be determined.

In addition, a program to determine the micro-water balance across the tailings surface under both vegetated and barren conditions will be instituted. This program will include the use of twinned plots, instrumented so that the pertinent fluxes of water and energy at the surface can be determined. The program will include the following components:

- automated recording rain gauge
- precipitation chemical sampler
- 20-point snow course
- two "twinned" 5x5 m runoff plots with flow measurement devices
- 2 Ott (OTT) water level meters
- 25 observation wells for manual measurement
- 25 piezometer nests (5 bundles each nest) entire basin
- 5 observation wells for continuous recording
- 5 multi-level samplers, 10 levels in each
- 5 neutron probe access tubes
- shallow tray lysimeters
- 1 Campbell CRF datalogger
- single-level windspeed
- single level net allwave radiation
- single level temperature and humidity
- 20 ground temperature measurements

This instrumentation will permit accurate estimates of the surface water balance. The "twinned" plots will give an untreated control, and are planned for surface treatment. The first year should include a snow melt, likely to be an important feature of the hydrology of the area.